TECHNICAL MANUAL

ARMY COMMUNICATIONS FACILITIES

OPERATIONAL

ELECTROMAGNETIC

COMPATIBILITY

HEADQUARTERS, DEPARTMENT OF THE ARMY

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OPERATIONAL ELECTROMAGNETIC COMPATIBILITY

LIST OF ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

1-1. Purpose
This manual is intended to provide guidance to operators of Communications-Electronics (C-E) equipments in identifying and resolving Electromagnetic Compatibility (EMC) problems. Guidance is provided for requesting outside assistance when EMC problems cannot be solved with in-house resources.

1-2. Scope
The procedures contained in this manual are to be standard practices for US Army station and facility communications operating personnel (technical controllers, repairmen, and attendants). Advice and guidance are provided regarding identification and resolution of EMC problems and methods to be used for reporting and submission of requests for assistance from technical support organizations.

1-3. Definitions
Refer to appendix.

1-4. Recommendations for Changes
Users of this manual are encouraged to submit recommended changes or comments to improve the publication. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment to ensure understanding and complete evaluation. Comments should be prepared on DA form 2028 (Recommended Changes to Publications and Blank Forms) and submitted directly to the Commander, US Army Communications Command, ATTN: CC-POA, Fort Huachuca, Arizona 85613

CHAPTER 2

TYPES AND CAUSES OF EMC PROBLEMS

2-1. General

a. Electromagnetic interference (EMI), commonly called "interference," is defined herein as any electromagnetic energy which degrades the performance of C-E equipment.

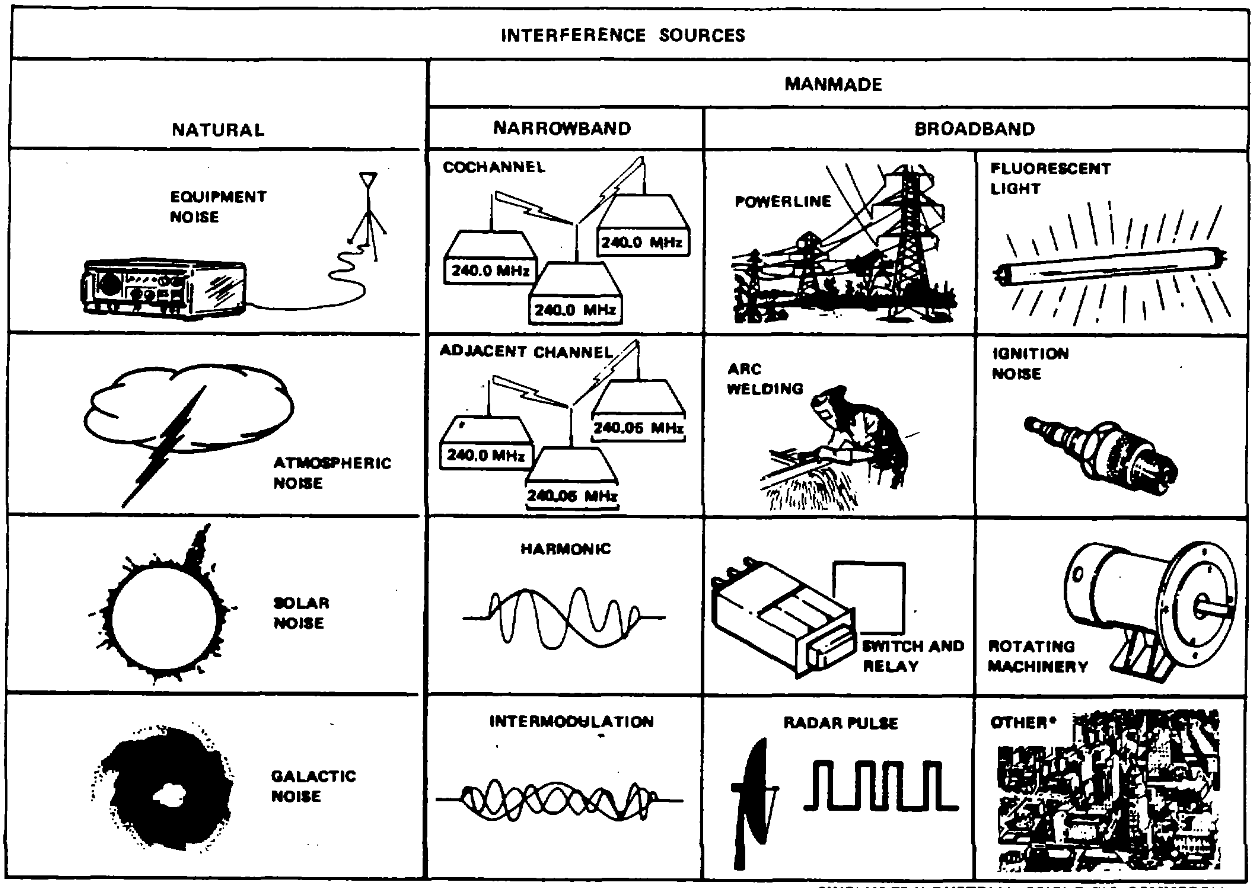
b. EMC problems resulting from interference are directly related to three factors: (1) interference sources, (2) transfer media, and (3) equipment susceptibility.

2-2. Interference Sources

a. *General.* Interference may result from either natural or manmade causes (fig 2-1). While the effects of interference from natural sources are geographically widespread, manmade interference (intentional or unintentional) usually affects only limited areas near the specific sources. An exception is high frequency (HF) interference which may emanate from distant radiations which have been refracted from the ionosphere.

b. Natural Interference Sources. These sources may be as close to the operator as his own equipment and the earth's atmosphere, or as distant as the sun and the outer reaches of the galaxy.

(1) *Equipment noise*. This noise, self-generated within electronic equipment, is generally traceable to either "thermal agitation" or "shot effect." Thermal-agitation noise is caused by the unequal flow of electrons across a circuit element from the effects of heat, resulting in a net voltage of random variation. Shot effect is caused by the random emission of electrons from an electron tube cathode. Noise in a semiconductor device is primarily caused by the random motion of majority carriers crossing a junction and by fluctuations in the relative amounts of current flowing from the emitter to the collector and base of a transistor. The noise power level of a semiconductor device is greater at the lower frequencies and depends upon the material of the semiconductors used. The types of noise described are strictly-speaking man-made, because the equipment is man-made. However, they are described here as "natural" to make a point. They do-not arise from fault conditions or from equipment maladjustment or any other conditions which can be remedied by operating personnel. Nor are they intentionally generated. The types of noise described are "natural" in the sense that they are always present to varying degrees in all energized electronic equipment and the extent to which they can be minimized in practice, is dependent on the funds available during the design and construction stages of the equipment.



*INCLUDES INDUSTRIAL, SCIENTIFIC, COMMERCIAL, AND MEDICAL APPARATUS

Figure 2-1. Typical interferences sources.

(2) *Atmospheric noise*. The primary source of atmospheric noise is lightning discharge in thunderstorms, which may result in a type of radio interference commonly referred to as static. An additional source of atmospheric noise is precipitation static, produced by rain, hail, snow, or dust storms. Atmospheric effects are erratic in character, consisting of short, randomly recurring bursts of noise which lack any regularity in phase or amplitude and which are spread throughout the RF spectrum. The average power level of atmospheric noise is relatively constant over short periods of time, but may vary considerably over longer periods of time. Atmospheric noise levels depend upon such factors as frequency, time of day, season, equipment location, and weather conditions. Atmospheric noise becomes significant at frequencies below 50 MHz, and dominates all other natural interference sources below 30 MHz. This noise is usually the limiting factor in communications below'30 MHz.

(3) *Solar noise*. Solar noise increases during periods of high sunspot or solar flare activity and decreases during periods of low activity. The periods of high activity may last several days at a time, and noise levels may be 10 to 20 dB greater than the levels associated with low activity. During a sunspot or solar flare activity, noise will first be noticed at the higher end of the high frequency (HF) region, then at the lower end as the disturbance matures. At times, the RF spectrum of these outbursts is quite wide and involves a major portion of the radio frequencies now in use.

(4) *Galactic noise*. Galactic noise originates beyond the solar system from a number of sources within the heart of the galaxy; that is, the Milky Way. Galactic noise intensity varies with frequency and position within the galaxy, being strongest in the direction of the galactic center (the constellation Sagittarius). On the surface of the earth, galactic noise is normally confined to ultrahigh frequency (UHF) and very high frequency (VHF) regions.

c. Manmade Interference Sources. Manmade

interference is most prevalent near densely populated areas and industrial districts, or within any other region where many transmitters and other interference-producing equipments are operating simultaneously. Also included in this category are such ancillary equipments as electric motors and generators. This type of interference is grouped into two categories: narrowband and broadband.

(1) *Narrowband interference*. Narrowband interference sources consist of cochannel, adjacent-channel, harmonic, and other signals at distinct frequencies as described below:

(a) Cochannel and adjacent-channel operation. A transmission from a distant station, although fully authorized, may become a source of interference if it is unintentionally received along with a desired signal. This situation is usually prevented by assigning cochannel frequencies to equipments only with adequate geographical separation. Adjacent channel operation may require some geographical separation also; however, receiver selectivity usually provides rejection of undesired adjacent channel signals. Conditions which cause cochannel and adjacent channel interference, then, include unusual propagation conditions (which cause distant transmitters to appear to be local RF sources); frequency spectrum crowding (which may result in adjacent channels being occupied by transmitters at power levels that override receiver selectivity); use of excessively high, unauthorized power levels; and lack of proper maintenance procedures (which can result in off-frequency operation through transmitter frequency drift and lack of selectivity at the receivers). Note that, for the purpose of this discussion, a channel is defined as an assigned frequency range of a given portion of the RF spectrum and may include from 1 to 2700 audio channels.

(b) Harmonics of the transmitted frequency and other spurious emissions. Harmonics of the transmitted frequency and other nonharmonic spurious emissions are always present to some degree in the radiated output of a transmitter. Well-designed transmitters, maintained in good operating condition and properly loaded into antennas, will radiate only very low-level spurious emissions. Improper tuning, loading, and maintenance, and faulty transmitter and antenna elements can cause normally low-level spurious emissions to increase to extremely high levels. These signals are primarily generated in the frequency multiplier or RF power amplifier stages of the transmitter. In addition, harmonics and other nonharmonic spurious emissions of the transmitter local oscillator (LO) may be radiated. An example is presented in figure 2-2, which shows the transmitter spurious emission measurements on an AN/GRT-22 transmitter. Frequently, interference is caused by spurious emissions from a transmitter, rather than from a transmitter operating on the desired frequency. Frequency allocation plans usually prohibit two transmitters operating on the same frequency if the antenna patterns and service areas are such that interference could be caused.

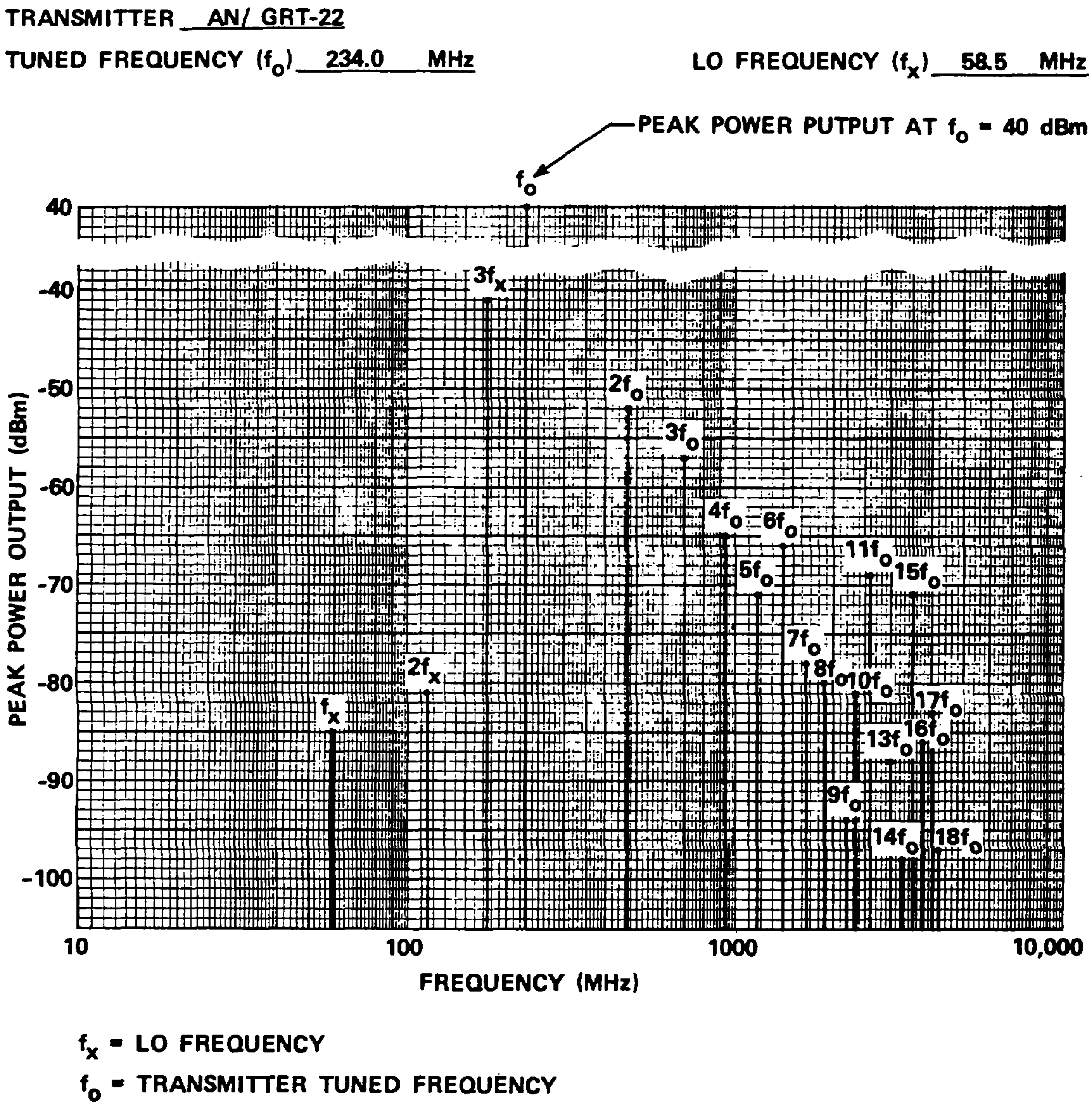


Figure 2-2. Transmitter spurious emissions for an AN/GRT-22.

(*c*) *Intermodulation and cross modulation*. Intermodulation, the combining of RF signals in a receiver front end or transmitter final stage, and cross modultion, the superimposing of the modulation of an undesired signal on a desired signal, occur as a result of circuit nonlinearities. A nonlinear circuit is one which does not pass or amplify all voltage levels or voltage polarities equally. Circuit nonlinearities may occur from such simple causes as corroded or loose antenna connections and waveguide hardware, foreign material inside waveguides, electron tubes whose operating characteristics have changed through use, and changes in circuit resistance or capacitance values as a result of overheating or aging, all of which illustrates the importance of preventive and corrective maintenance procedures. An overdriven amplifier becomes a nonlinear device which clips or

distorts an applied signal. An example of nonlinear operation of a transistor is shown in figure 2-3. This figure shows the manner in which the output voltage waveform becomes distorted as a result of operation over the nonlinear portion of a transistor's base current versus collector current operating curve. This distorted output contains frequencies which were not present in the sine wave input signal. These are actual frequencies which comprise the distorted output signal in that they respond to such actions as filtering, coupling, and frequency selection as though they had been input to the circuit. In the case of two or more RF signals being presented to an RF amplifier under such nonlinear conditions, sum and difference intermodulation product frequencies can be produced. Many nonlinear devices are used to perform useful operations, such as within a mixer stage where the nonlinearity is used to heterodyne or beat the incoming signal frequency with the local oscillator frequency to produce an intermediate frequency. A diode is a nonlinear device which may be placed in a circuit so as to pass only the positive going voltage peaks, while shunting the negative going peaks to ground. However, when the RF amplifier of a receiver is nonlinear, or is operated over a nonlinear portion of its characteristic curve (overdriven), it has the potential for producing cross modulation and interlmodulation products. Either of these types of distortion is objectionable.

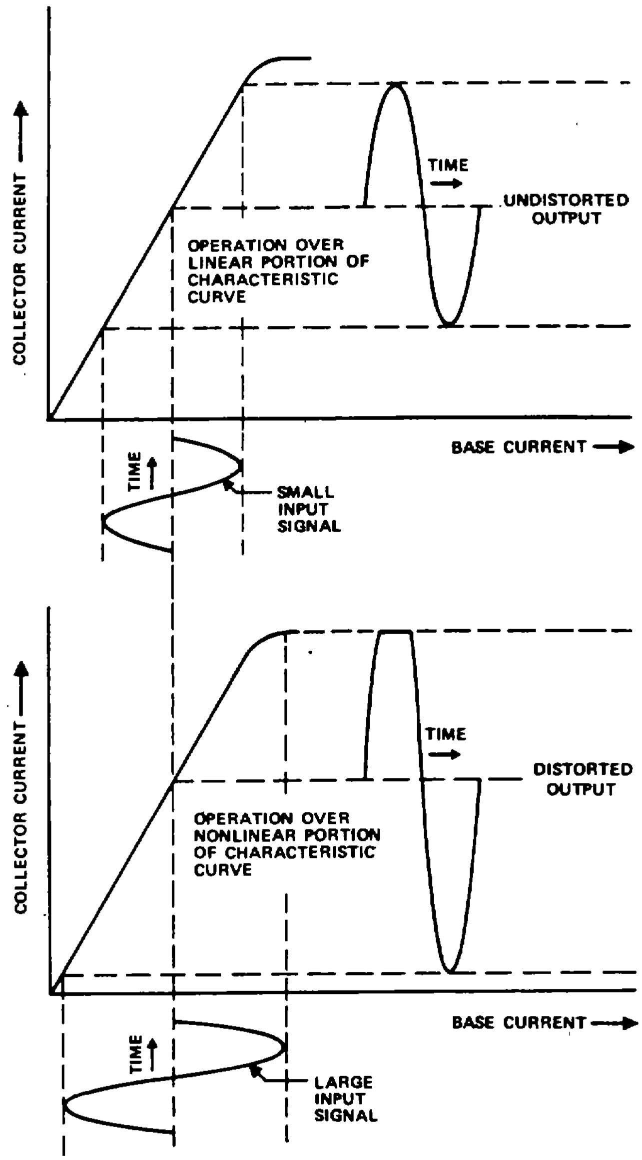


Figure 2-3. Example of distortion as a result of overdriving an amplifier stage.

1. Cross modulation, in contrast with intermodulation, does not involve the mixing of two RF signals to result in intermodulation products at different frequencies, although it does occur as a result of circuit nonlinearities. If a nonlinearity exists, such as an overdriven RF amplifier stage, an amplitude modulated adjacent channel signal will cause the gain of the amplifier to vary with the modulation. In effect, this modulation is transferred to the desired signal as it progresses through the amplifier. The possibility of experiencing cross modulation problems as well as intermodulation problems can be decreased by following good maintenance practices including proper receiver alignment to maintain designed selectivity and linearity characteristics, maintaining good electrical connections, and replacing components as needed to maintain optimum operational performance.

2. Intermodulation frequencies may be produced at a receiver when two signals are simultaneously received which, although they may be outside the RF bandwidth of the preselector stage, override the preselection and are presented to the RF amplifier (fig 2-4). If a nonlinearity exists within the RF amplifier which allows the mixing of these two signals, intermodulation frequencies will be produced according to the following equation:

$$f_I = mf_1 \pm nf_2$$

where

f_I = intermodulation frequency

f_1 = frequency of interference closest to the receiver tuned frequency

f_2 = frequency of interference farthest from the receiver tuned frequency

m and n = integers (1,2,3 and so forth) Any frequencies produced which fall within the RF bandwidth of the filter following the RF amplifier will be presented as false desired signals to the mixer stage. The resulting demodulated signals will appear at the audio output. As an example of the production of an intermodulation frequency, consider the following example from experiments on the AN/GRR-23 receiver: In this experiment, a squelch break occurred with no desired signal present when two signals at 139.8 and 140.2 MHz were transmitted in the vicinity of the victim receiver. The intermodulation frequency responsible for this squelch break was found to be 139.0 MHz, the tuned frequency of the receiver. Although both frequencies, 139.8 and 140.2 MHz, were outside the RF bandwidth of the receiver, their combined effect was to cause a squelch break to occur. Analysis revealed that the intermodulation frequency responsible was of the 5th order, calculated as follows:

$$\begin{aligned} f_I &= 3f_I - 2f_2 \\ &= 3(139.8) - 2(140.2)\ \text{MHz} \\ &= 419.4 - 280.4\ \text{MHz} \\ &= 139.0\ \text{MHz} \end{aligned}$$

Therefore, $f_I = f_0 = 139.0$ MHz.

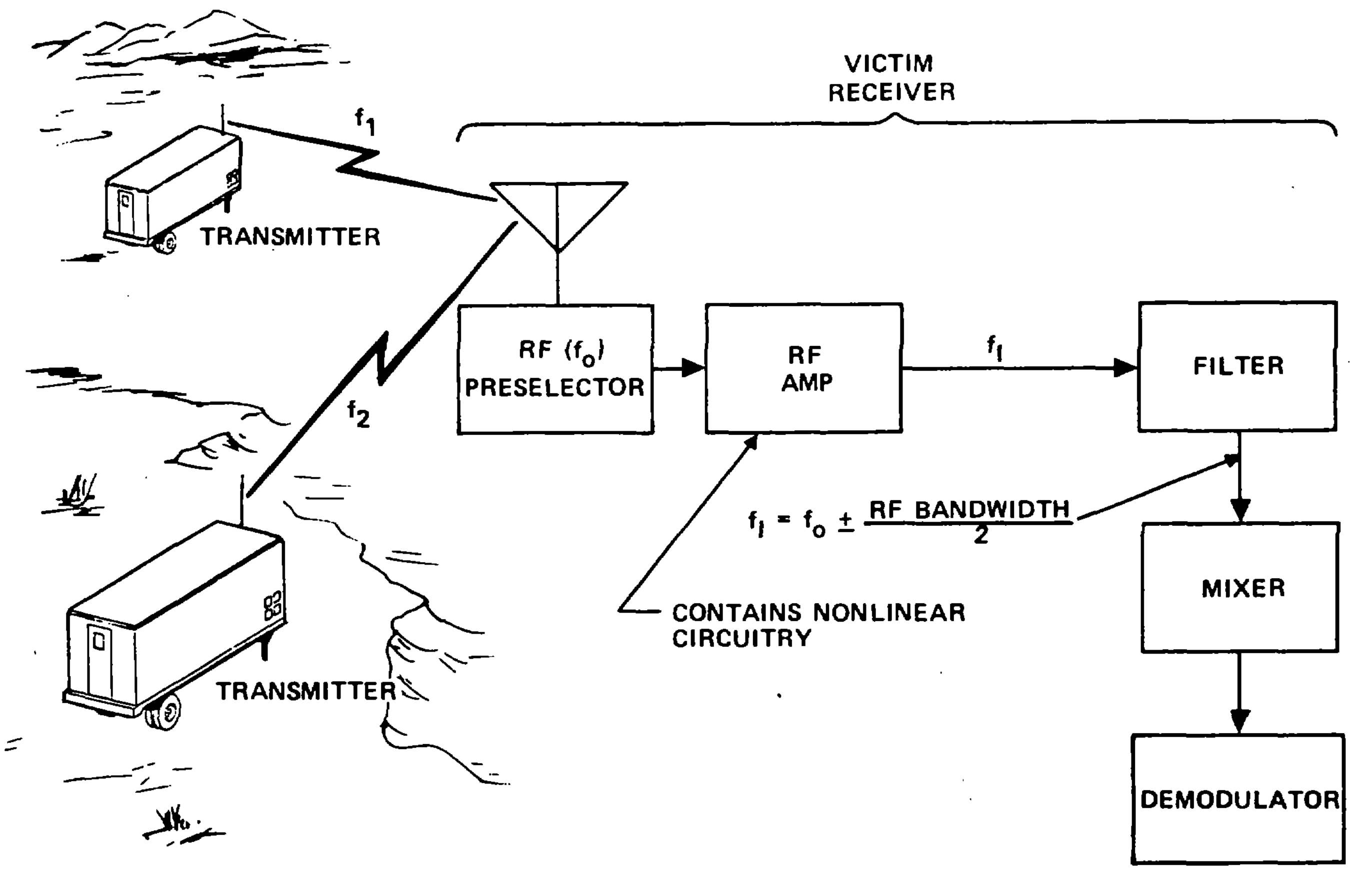


Figure 2-4. Intermodulation products occurring at a receiver.

3. Intermodulation products may also occur in a link transmitter as a result of the mixing of signals from two interfering transmitters in the final stage of the link transmitter. Intermodulation products are generated in the final stage according to the' same equation presented for receiver intermodulation products. The transmitted signal consists not only of the desired signal, properly modulated, but the intermodulation products also at the desired signal frequency (or, at least, within the RF bandwidth of the link receiver). The intermodulation product signals will contain vestiges of the interfering signal modulations which will be heard as noise at the link receiver. An example of the production and transmission of 7th order intermodulation products which could interfere with a 50-MHz link is shown in figure 2-5. Interfering signals entering the link transmitter antenna are mixed in the final stage and retransmitted as 7th order intermodulation product signals according to the following relationship:

$$
\begin{aligned}
f_I &= 4f_a - 3f_b \\
&= 4(51.2) - 3(51.6) \text{ MHz} \\
&= 204.8 - 154.8 \text{ MHz} \\
&= 50.0 \text{ MHz}
\end{aligned}
$$

Therefore, $f_I = f_0 = 50.0$ MHz.

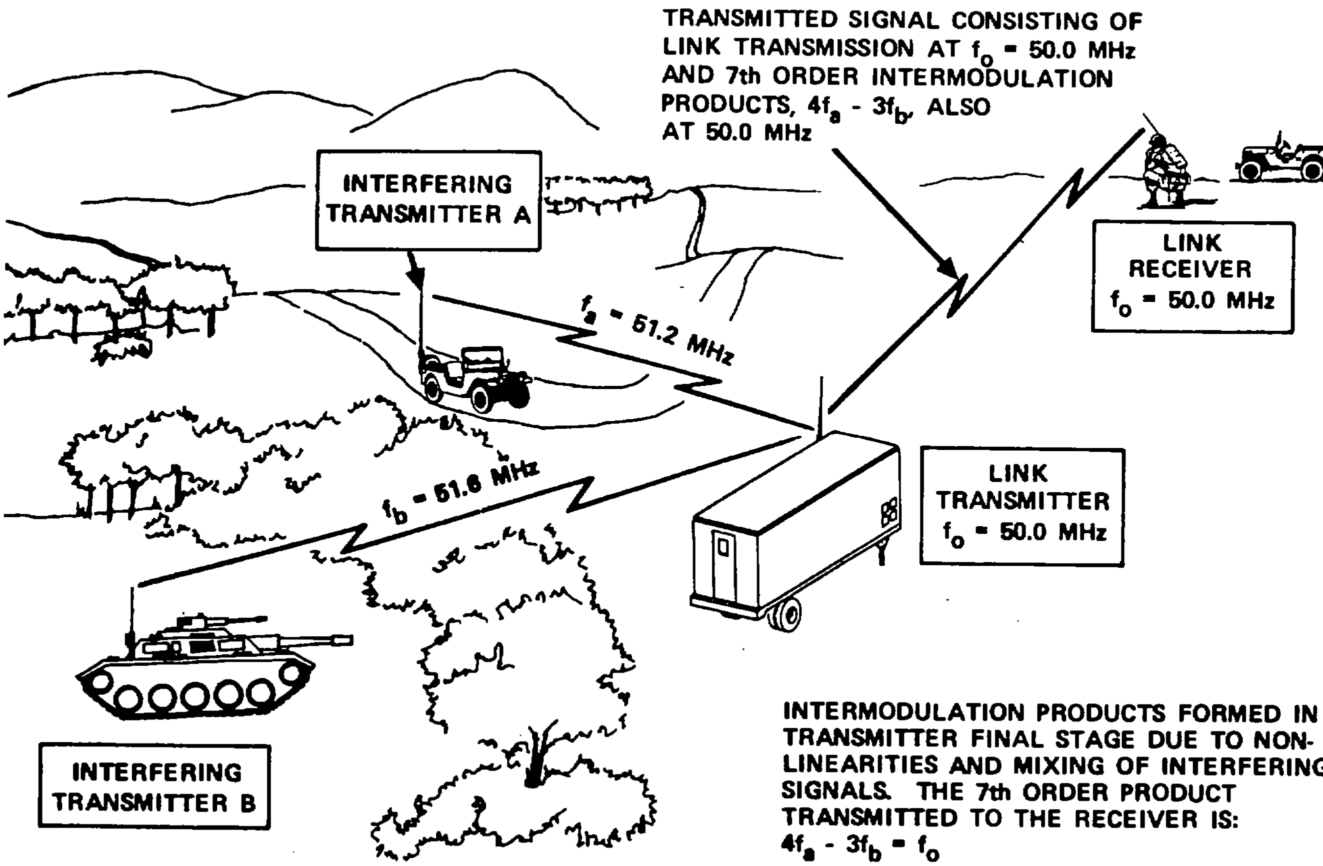


Figure 2-5. Intermodulation products occurring at a transmitter.

4. Coupling of transmitter signals which result in cross modulation and intermodulation may occur through radiation from one transmitting antenna to another and conduction by means of the normal transmission line; through conduction from one transmitter to another due to improper grounding or bonding; or through radiation from a transmitter antenna or improperly shielded, bonded, or grounded transmitter to another transmitter which is also improperly shielded. Frequently, it has been found that poor or rusting connections on guy wires for antenna supports or power lines can cause serious interference problems. As has been shown, intermodulation products may be produced at many sum and difference frequencies when the fundamental frequencies of two transmitters are present in the same nonlinear element. Interference may also occur when three signals mix in a nonlinear element. The sum frequency of two of the signals may produce a difference frequency with a third signal. Of importance are the intermodulation products which fall in the same or adjacent channel of the band in which the desired link equipment is operating. These are the products resulting from such combinations as:

$2f_a - f_b$, $2f_b - f_a$, $3f_a - 2f_b$, and $f_a + f_b$ - fc.

Higher order frequency intermodulation products are usually not detected, even though they are present, because they are of a very low power level.

(*2*) *Broadband interference*. Broadband interference is characterized by noise emission which extends over a wide frequency range. One means by which wideband interference is produced is the periodic opening and closing of a current-carrying circuit, which causes sudden voltage changes (signal transients containing steep wavefronts). These transients are composed of many frequencies that are even multiples (harmonically related) of the occurrence rate of closing and opening the circuit. Undesirable responses appear in a receiver throughout a broad tuning range when signals at these frequencies are radiated and detected. Interference sources of this type are discussed in (a) through (h) below.

(*a*) *Powerline*. Powerline interference is a result of any sudden change of voltage which may accompany surges, corona, sparking, or the interruption of an electric power circuit. Typical sources of powerline interference are: insulators

covered by dust or other material deposited from the air. damaged insulators, excessive voltage, loose tie wires or connectors to the powerlines, insulation breakdown in transformers or capacitor banks, intermittent contact between any two metallic objects on power poles, poor ground connections between a neutral line and earth, and any sharp points projecting from powerlines.

(b) Fluorescent lights. Transients may be generated by the normal ionization of fluorescent lights within the tube or by defective starter and ballast units. The interference from fluorescent lights may arrive at a receiver by direct radiation of the steep wavefronts from the tube to the receiver antenna, by conduction from the light fixture through the powerline, or by radiation or conduction from the tube to the powerline and reradiation to a receiver antenna.

(c) Arc welding equipment. Interference may be caused by the transients associated with a welding arc. The interference may be suppressed by proper shielding, bonding, bypassing, and grounding. Welding equipment in general should be located in a position permitting the shortest possible grounding connection to earth. High capacity, reactance-type welders of the type used in industry are usually equipped with adequate suppression components. However, lack of proper maintenance of these units may result in interference radiation over a broad frequency range for long distances. When units of this type are found to be creating interference, they should be inspected and any loose connections, broken bonding straps, defective filters, or defective bypass capacitors should be repaired or replaced.

(d) Ignition noise. The interference caused by transients in vehicular ignition systems is usually most troublesome in the lower portion of the VHF frequency range (30-150 MHz). It is, however, detectable at frequencies of 0-500 MHz. Instances have been recorded of interference being detectable and in some cases troublesome at distances greater than 500 feet from its source. Arcing produced in the low-tension side of the ignition system by the contact-breaker points and sparking in the high tension system by the spark plugs is usually responsible. Additional sparking may occur if the ignition harness is defective. Steep wavefronts, associated with the electromagnetic fields produced by the arcing and sparking processes, contain many potential interference frequencies which may radiate directly from the discharge, from lowor high tension wiring, or from any metallic object not properly bonded or grounded.

(e) Switches and relays. All switches cause essentially the same types of interference, whether electrical, thermostatic, or electromechanical in operation. A switch is a device that can abruptly change its electrical impedance from zero to infinity or from infinity to zero. Transients throughout the circuit. which result in generation of broadband emissions, may cause interference. A relay is a switch whose contacts are opened and closed mechanically by an actuator controlled by the electrical field of a coil when an electrical signal is applied to the coil (electromechanically actuated). In the case of manually actuated switches, the emission produced is generally of relatively short duration unless there are capacitors or inductors in the circuit. Usually such emission is either nonrepetitive or is repetitive at a slow or irregular rate. Switching interference is more severe when large current values or highly inductive circuits are involved because electrical discharge across switch contacts (without capacitor protection) when making or breaking circuits greatly intensifies the interference in both level and duration. Electromechanically actuated switches such as relays, vibrators, and buzzers create exactly the same type of broadband emissions as do manually actuated switches, but usually at a faster rate. Repetitive interrupters, such as vibrators, produce the same broad spectrum emission on a continual basis. The steep wavefronts thus generated are possible sources of interference. The signals present in these steep wavefronts may be radiated directly to a receiver antenna or they may be induced into the vibrator solenoid and conducted through power and control lines.

(f) Rotating machinery. Interference is generated in rotating machinery (e.g., motors or generators) due to the transients from brush bounce, commutator surface irregularities, brush arcing, and static discharge. Any rotating machinery with sliding contacts may be regarded as a potential source of electrical interference. A motor with clean commutator contacts generates less interference than one with rough, dirty contacts. The switching and arcing process of commutation causes rapid current and voltage changes which distribute interference energy throughout a wide frequency range. Another source of interference may be static discharges between a rotating shaft and bearing surface brought on by the insulation or dielectric effect of the lubricating film.

(g) Radar pulse. The radar output signal (pulse train), generated as it is by very rapid voltage changes and radiated as periodically occurring bursts of electromagnetic energy, contains frequencies which spread over a wide band. These frequencies consist of a wide range of harmonics of the basic frequency of occurrence of these pulses, which is the pulse-repetition frequency, as well as at the harmonics

of the radar's carrier frequency. If the radar antenna radiating this train of pulses sweeps in a circular arc, the intensity of the pulses will seem to vary in intensity as heard at a fixed radio station. Radar pulse interference may be radiated from any metallic portion of a radar system structure as a result of coupling from the circuit components which convey the pulses.

(h) Industrial, scientific, commercial, and medical apparatus. Any apparatus using RF energy can be a serious source of interference. Such apparatus may be diathermy equipments, X-ray machines, microwave ovens, or induction heaters. Electromagnetic interference is radiated directly from the apparatus or conducted along the power and control lines. This type of interference may travel hundreds of miles and often cannot be detected in the area between the source and the receiver being disturbed.

2-3. Transfer Media

a. General. If electromagnetic energy is to cause interference, it must be transferred from the point of generation to the location of the susceptible device. This transfer may occur over one or more paths by means of conduction, radiation, or combinations of these two modes of transfer.

b. Conduction. Interference by conduction occurs when signals are transferred unintentionally between two circuits by an actual circuit element which is shared by the two circuits (common impedance), or by an effective common impedance (although no actual shared circuit element is present), caused by the proximity of circuit wiring. A complete circuit must exist; that is, there must be a signal path and a return path between the affected circuits. Sometimes these paths and effective common impedances are not readily apparent, but they can occur, for instance, by direct wiring or use of a common ground. Coupling of undesired signals by means of common connections, especially on the ground side, is a frequent occurrence. Further description of interference coupling by conduction is contained in (1) through (3) below (see also para 2-4, Equipment Susceptibility):

(1) Two circuits are said to be mutually coupled whenever voltages or currents in one circuit induce corresponding voltages or currents in the other circuit. The sharing of a wire or a junction point between two or more circuits (common interconnection) can result in common impedance coupling, whereby current in one circuit causes a voltage to appear in another circuit. The interference voltage level so produced is dependent upon the magnitude of the common impedance and the current flow through the impedance. Circuits characterized by high impedance (and low power levels) are highly susceptible to interference, especially from higher power circuits that share a common impedance. The so-called ground loop, where undesired signals are transferred from a highpower circuit to a low-power circuit as a result of the impedance shared in a common ground circuit resulting from a poorly designed ground system or poor ground connection, is one example of this.

(2) Two conductors close together tend to produce voltage variations within their circuits through mutual capacitance. The capacitive reactance between two conductors varies with the distance between the conductors, conductor sizes, and the frequency of the signal being coupled. The effect of capacitive coupling increases with increasing frequency. The use of a shield (or shielded wires in the case of conductors in proximity) will reduce the interference.

(3) The various circuit interconnecting equipments at a communications site cause closed loops to exist with mutual inductance acting as the mechanism for interaction between the loops. This interaction may be thought of as a transformer action between the interference source and the sensitive circuit. Circuits characterized by low impedances are particularly susceptible to inductive coupling. The effect increases with increasing frequency and decreasing distance separation. The use of a magnetic shield or the repositioning of equipments or wiring can reduce inductive coupling.

c. Radiation. Electromagnetic radiation of an electrical signal involves propagation through a medium; therefore, the effects on the signal by the medium must be considered. During transmission of an interfering signal, losses are incurred which can render the signal harmless. If not enough loss is involved, however, the undesired signal will reach a receiver as interference. When signals are radiated through the medium of the earth's atmosphere, the losses incurred in transmission are dependent upon frequency, separation distance (the distance from the emitter of the signal to the receiver), terrain over which propagation occurs, and the electromagnetic properties of the transmission medium (which change with day and night, seasons, weather, and ionization effects of the sun).

(1) Table 2-1 shows the propagation characteristics of the RF spectrum. The three types of radio wave propagation represented in this table are, in the order of increasing frequency, ground waves (propagated over the surface of the earth and influenced by the ground as well as the troposphere, the atmospheric region immediately above the earth), skywaves (propagated by refraction effects of the ionosphere, the region above the troposphere), .and troposphere scatter waves (propagated by

reflections at abrupt changes in the troposphere). Along the surface of the earth, the maximum distance that a ground wave is effective decreases with increasing frequency of the wave. Ground waves undergo deviation from normal, straight-line travel by contact with the troposphere, refraction, reflection from path discontinuities, diffraction, and propagation along the curved surface of the earth because of the earth's conductivity. It is for these reasons that ground wave propagation extends beyond the line-of-sight distance. Skywaves and tropospheric scatter waves undergo deviation in direction along their propagation paths as a result of diffraction, reflection, and refraction as they encounter variations in the media through which they travel. All of the above factors, in addition to absorption of the energy of the radio waves, are responsible for propagation path losses encountered by radiated signals and the "freakish" interference which results from distant, low-power transmitters.

Table 2-1. Propagation Characteristics of the RF Spectrum

Frequency	Band	Propagation characteristics	Typical uses
Below 3 kHz	ELF	Primarily ground waves; low attenuation, reliable, daytime absorption of skywaves greater than at night	Very long distance point-to-point (greater than 1000 nautical miles)
3-30 kHz	VLF	Same as ELF, except attenuation equally low, day or night; reliable	Very long distance point-to-point. Tactical broadcast communications
30-300 kHz	LF	Same as ELF	Long and medium range (50 to 1000 nautical miles point-to-point communications, marine, navaids
300-3000 kHz	MF	Ground waves, but also some ionospheric skywaves; attenuation of skywaves low at night and high in daytime. Subject to ground-skywave interference for distances less than 500 nautical miles.	Broadcasting, marine communications, navaids, harbor telephone, medium and short range
3-30 MHz	VHF	Primarily skywave transmission over great distances, depending on ionosphere. Varies, greatly with time of day, season, frequency, and portion of solar sunspot activity cycle. Subject to ground-skywave interference at short distances	Moderate and long distance communications of all types
30-300 MHz	VHF	Primarily line-of-sight transmission. Sporadic ionosphere effects occur during high portions of solar sunspot cycle	Short distance, line-of-sight communications, television, FM broadcasting, navaids, radar, troposcatter communications, aero-navaids
300-3000 MHz	UHF	Substantially straight-line propagation analogous to that of light waves. Unaffected by ionosphere	Short-distance communications, radar, television, aero-navaids, point-to-point relays, troposcatter communications
3-30 GHz	SHF	Same as UHF	Short-distance communications, radar, point-to-point relay systems, navaids, satellite relays, tropospheric scatter communications

Bands
ELF =Extremely low frequency
VLF =Very-low frequency
LF =Low frequency
MF = Medium frequency
HF= High frequency
VHF= Very-high frequency
UHF= Ultra-high frequency
SHF= Super-high frequency

(2) The ionosphere is a region of the earth's upper atmosphere which lies between about 40 to 50 km above the earth out to about 12,000 km above the earth. There are within this space three ionized layers or "regions," referred to as the D, E, and F regions, occurring at approximate heights of 50-90 km, 90-130 km, and above 130 km, respectively. These regions are believed to be generated by ultraviolet light and "soft" X-rays from the sun. Radio waves propagate through, or are reflected and refracted by, these regions, depending on the frequency of the waves and the angle of incidence of the wave front related to the layers. The regions are not uniform around the earth, but, since they are

affected by radiation from the sun, some portions of the regions may be more heavily ionized than other portions. This can disrupt long-distance HF radio communications.

2-4. Equipment Susceptibility

a. General. Any equipment or device capable of responding to electromagnetic fields or to electrical signals must be considered susceptible to electromagnetic emissions. Whereas paragraphs 2-2 and 2-3 described the generation and transmission of interference signals, this section deals with the reception of, and reaction to, these signals by various equipments. Two broad categories of equipment can be established: those that are frequency selective and those which are not frequency selective.

b. Entry Mechanism. In paragraph 2-3 it was stated that undesired signals are transmitted by conduction or radiation, or both. There are three means by which an undesired signal may enter equipment: (1) through a common interconnection, (2) through capacitive and inductive coupling, and (3) through direct impingement of electromagnetic energy. Figure 2-6 depicts examples of these entry mechanisms. In figure 2-6A, undesired signal current is conducted from its source in equipment A to the receiving unit, equipment B, through common input leads. The use of common power supplies not properly isolated electrically (decoupled), or improperly operating multiplexing equipment are examples where this type of entry is possible. Another means of entry through the common interconnection is shown in figure 2-6B. Even though the common connection point is ground, it must be remembered that some impedance may be present which is shared by the two signal paths and, therefore, coupling between the circuits takes place. This type of coupling is commonly encountered as a result of poor equipment design, installation, or maintenance, and may be minimized by correct design of the ground system. Figure 2-6C shows an example of the entry of undesired signals through capacitive and inductive coupling between signal lines placed close together. This type of coupling can occur between multiple signal and control lines, other signal lines, adjacent power lines, and transmission lines. Direct impingement of electromagnetic energy as a means of undesired signal entry is shown in figure 2-6D. Electromagnetic energy can also gain direct entry into equipments through ventilation holes, meter and other panel openings, and inadequate shielding, or indirect entry by causing currents to be induced in equipment cabling, connectors, and other wiring. The latter cases usually originate within a system or equipment and may be regarded as intrasystem coupling.

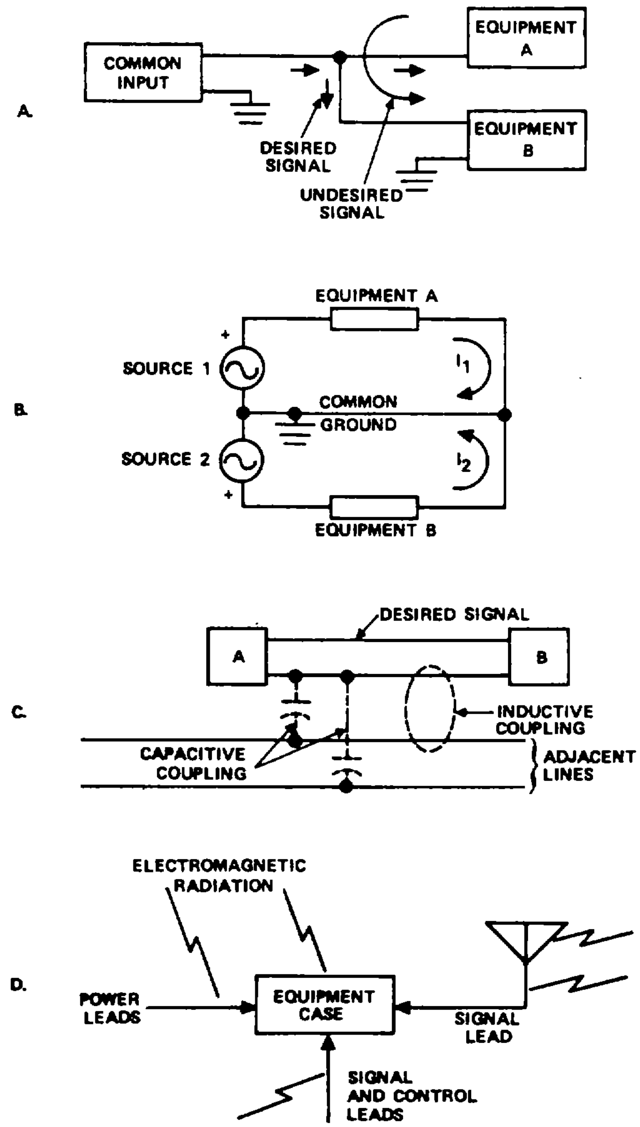


Figure 2-6. Interference signal entry paths.

c. Equipment Susceptibility Characteristics.

(1) Frequency Selective Equipment. Frequency selective equipment includes all equipment types which operate at fixed frequencies or which are tunable over a selected range of frequencies. Communications receivers are subject to more numerous, more complex interference situations than other equipment types because of their highly sensitive front end circuits and the fact that so many users must share the RF bands. A discussion of typical interference situations follows:

(a) Cochannel and adjacent channel interference. Any transmission may interfere with another system if it is present simultaneously with a desired RF signal. This interference can occur when two transmitters have been assigned to operate on

the same frequency or channel or when the transmitters have been assigned adjacent channels. Interference occurs when the carrier frequency or sideband frequency of the interferer is within the bandpass of a victim receiver (fig 2-7 and 2-8).

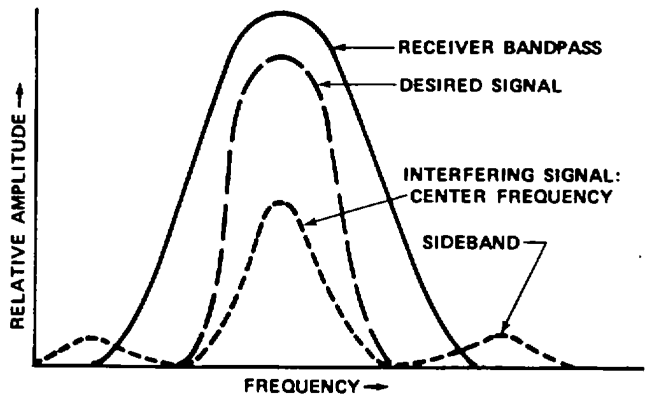


Figure 2-7. Cochannel interference.

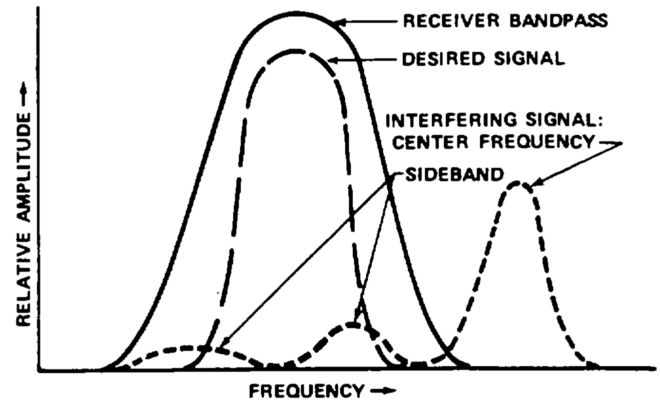


Figure 2-8. Adjacent-channel interference.

(b) Intermediate-frequency interference. A form of interference known as intermediate frequency (IF) interference may occur if a high-amplitude signal at the receiver IF reaches the mixer or IF stage (fig 2-9) through the receiver antenna and front end, or through the equipment case or cabling. Since the IF of a receiver normally remains constant through the tuning range of the receiver, this type of interference is characterized by its presence at all tuned frequencies of the receiver.

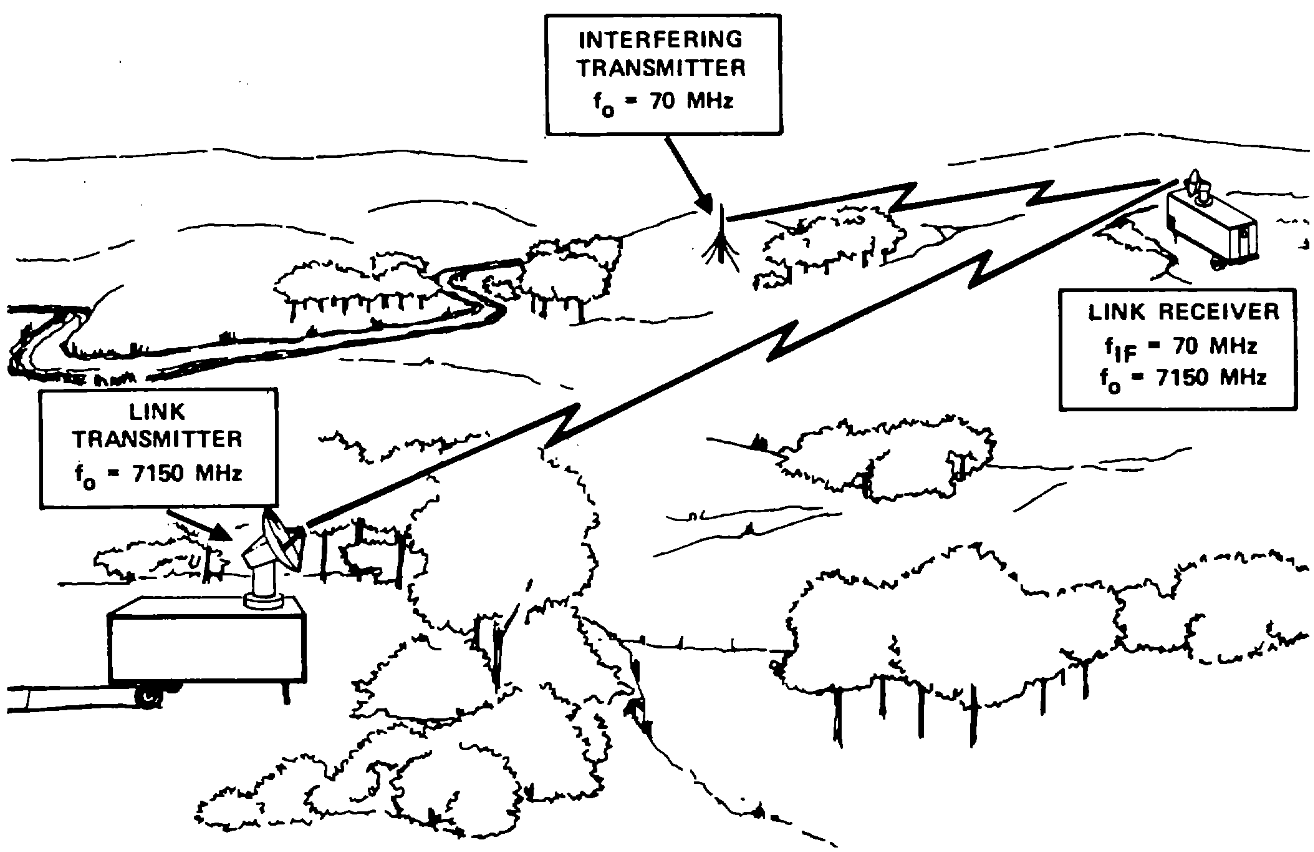


Figure 2-9. Intermediate-frequency interference.

(c) Spurious response interference. In addition to the susceptibility of receivers to cochannel. adjacent channel, and IF interference, most receivers may also be susceptible to interference at other frequencies because of their "spurious" response characteristics; that is, their response to frequencies other than the tuned frequency of the receiver. Most spurious response characteristics are the result of nonlinear elements of the RF circuitry (front end) as well as in the mixer stage. which is designed to be nonlinear. Although a signal may be relatively free of harmonic content, harmonics of the signal may be generated in the receiver front end whenever a nonlinearity is encountered. Such nonlinear elements include mixer stages and, frequently, antenna grounds or other signal connections (oxide films formed on the metal by corrosion), cold solder joints, and overdriven RF stages. An input signal will mix with local oscillator harmonics. harmonics of an input signal will mix with the local oscillator signal, or combinations of both may occur. If any combination of harmonics produces a signal at the same frequency as the IF, at the mixer stage output, interference may occur. Most spurious responses (f_{sp}) can be identified by the following relationships:

For a single-conversion receiver:

$$f_{sp} = \frac{pf_{LO} \pm f_{IF}}{q}$$

For a dual-conversion receiver:

$$f_{sp} = \frac{p_1 \; f_{LO_1}}{q_1} \pm \frac{p_2 \, f_{LO_2} \pm f_{IF_2}}{q_1 q_2}$$

Where p is an integer or zero denoting the harmonic order of the local oscillator: q is an integer denoting the harmonic order of the spurious response frequency; fu and f_{IF} denote the local oscillator and intermediate frequencies, respectively. the numerical subscripts indicate the number of conversions preceding the section of the receiver of concern, and the positive and negative signs identify different spurious responses. As an example of spurious response identification, consider the AN/FRC109(V) tuned to 7680 MHz. The local oscillator frequency is 7750 MHz and the intermediate frequency is 70 MHz.

For p = 2, q = 2 and sign of(—):

$$f_{sp} = \frac{pf_{LO} \pm f_{IF}}{q}$$

$$f_{sp} = \frac{2(7750) - 70}{2} = 7715 \text{ MHz}$$

In other words, the second harmonic of the spurious signal frequency mixes with the second harmonic of the local oscillator frequency in the mixer stage to produce a potential interfering signal at 70 MHz which is identical to the IF of the receiver. The IF amplifier stages will treat this signal in the same manner as the desired signal.

(*d*) Communications receivers are susceptible to intermodulation and cross modulation interference resulting from simultaneous reception of two or more signals combined through circuit nonlinearities in the receiver front end. The result of this combining (mixing) may be the production of sum and difference frequencies within the receiver pass band which are converted to the intermediate frequency in the mixer, demodulated, amplified, and presented as noise in the audio output. The interfering signals do not have to be within the receiver's preselection pass band for this to occur. They must merely be of such sufficient strength as to override the selectivity capabilities of the receiver. Cross modulation may be apparent to the operator as an unclear signal, or as the receiving of two signals of different intensity.

1. Interference due to intermodulation may occur at a receiver when the frequencies of two signals are separated by an amount equal to the frequency to which the receiver is tuned. If two such signals are passed through a nonlinear element in the receiver front end, their sum and difference frequencies are generated by heterodyne action. These new frequencies are termed the A-B and A + B intermodulation products. When these frequencies are of sufficient amplitude and are within the receiver pass band, they will be detected in the same way as a desired signal.

2. Interference due to intermodulation may also result when the harmonic of one signal and the fundamental of any other signal combine to produce a sum or difference frequency equal either to the receiver tuned frequency or to a spurious-response frequency. Any multiple of the tuned frequency, such as 3A±2B, 3B±2A, 4A±3B, and so on, may cause interference of this type if it is of sufficient amplitude.

3. Interference due to intermodulation may also occur when three signals combine to generate the frequency to which a receiver is tuned. Two signal frequencies, when combined with a third frequency in a nonlinear element, will produce sum and difference frequencies. If these frequencies are equal to either the tuned frequency or a spurious-response frequency of a receiver, detection will take place and interference will occur. This frequency combination is termed the A±B±C intermodulation products.

(2) Non-frequency selective equipment. This term refers to all electrical and electronic devides other than those which are tunable to, or fixed at, a selected band of frequencies. In general, because of the complexity of types, arrangements, and operational characteristics of equipments, and because of the many types of interference-causing signals, entry modes, and interactions, the susceptibility characteristics of this equipment category have not been completely documented or standardized. Susceptibility of individual equipments used for specific requirements is best determined by test, either by simulation of interference signals or under actual operating conditions. A brief discussion of some susceptibility characteristics follows:

(a) Digital computers. Since operation of digital computers depends upon pulses and levels of fixed amplitudes occurring at predetermined times, computers are particularly susceptible to interference from pulsed signals (such as from radars sweeping the area). Experimental investigations of problems resulting from interference have demonstrated false switching in flip-flops (circuits designed to produce one of two possible outputs, depending on the last input signal received) and logic gates (circuits whose output depends on two or more input signals), deteriorated signals, and erroneous outputs. Computers are also susceptible to another type of interference which is worthy of mention, even though it is not electromagnetic. Computer memory banks are susceptible to magnetic fields and if these fields are of sufficient strength, data stored in the computer memory may be lost. Therefore, strong magnetic fields from either permanent magnets or electromagnets should not be allowed in the vicinity of computers.

(b) Control devices. This equipment category includes amplifiers which have low-level, high-impedance inputs and are used in the processing of sensor signals, control of electromechanical devices, and many other functions. Examples are servoamplifiers and dc amplifiers. Since this type of equipment frequently operates by controlling the amplitude of signals at the 60-Hz and 400-Hz powerline frequencies, they are particularly susceptible to powerline transients and stray coupling to wiring and transformers. Because they operate at relatively low signal levels, amplifiers of this type are troubled by common-mode coupling at their input terminals. Rectification (removal of positive or negative-going voltage peaks) of high-frequency signals by nonlinear circuit elements can cause saturation (operation at the maximum limit of response regardless of input voltage variations) or desensitization (lack of response to low-level signals) of gain characteristics, or parasitic (unintended, self-sustaining) oscillations.

(c) Displays. Cathode-ray tube displays are susceptible to emissions from radars, communication transmissions, ignition systems, and other equipments. The main effect is the disruption of the visual information presented to the equipment operator. Cathode-ray tubes are susceptible to stray magnetic fields which deflect the electron beam. Interference in sweep circuits is characterized by distortion of the display (by causing the sweep to be nonlinear), while undesired responses in the video sections may appear as intensity modulations. The circuits which process the video, or information signal, and those that generate the required sweep voltages are subject to powerline and common-mode coupling, as outlined in the previous section.

(d) Test equipment. Test equipment is just as susceptible to unwanted electromagnetic energy as many of the equipments under test. Powerline transients and capacitive and inductive coupling may produce false indications when testing equipment. Noise may be introduced into the test equipment as a result of a grounding problem and thus increase the indicated noise level.

CHAPTER 3

EMC PROBLEMS AS RELATED TO SIGNAL TYPES AND MULTIPLEXING TECHNIQUES

3-1. General

The manner in which the interference manifests itself in the system output will vary with the multiplexing technique and with the signal type being transferred over the system. These differences are important in the isolation and identification of EMC problems.

3-2. Signal Types and Multiplexing Techniques

a. General. Currently two basic types of signals are transferred over communications systems. One type, generally referred to as analog, uses the actual voice or other continuously variable waveform to modulate the transmitter directly. The other type, referred to as digital, transfers an original digital data stream or converts the input analog waveform to a digital bit stream of "ones" or "zeros" and uses this digital bit stream to modulate the transmitter. Typical analog and digital signals are shown in figure 3-1.

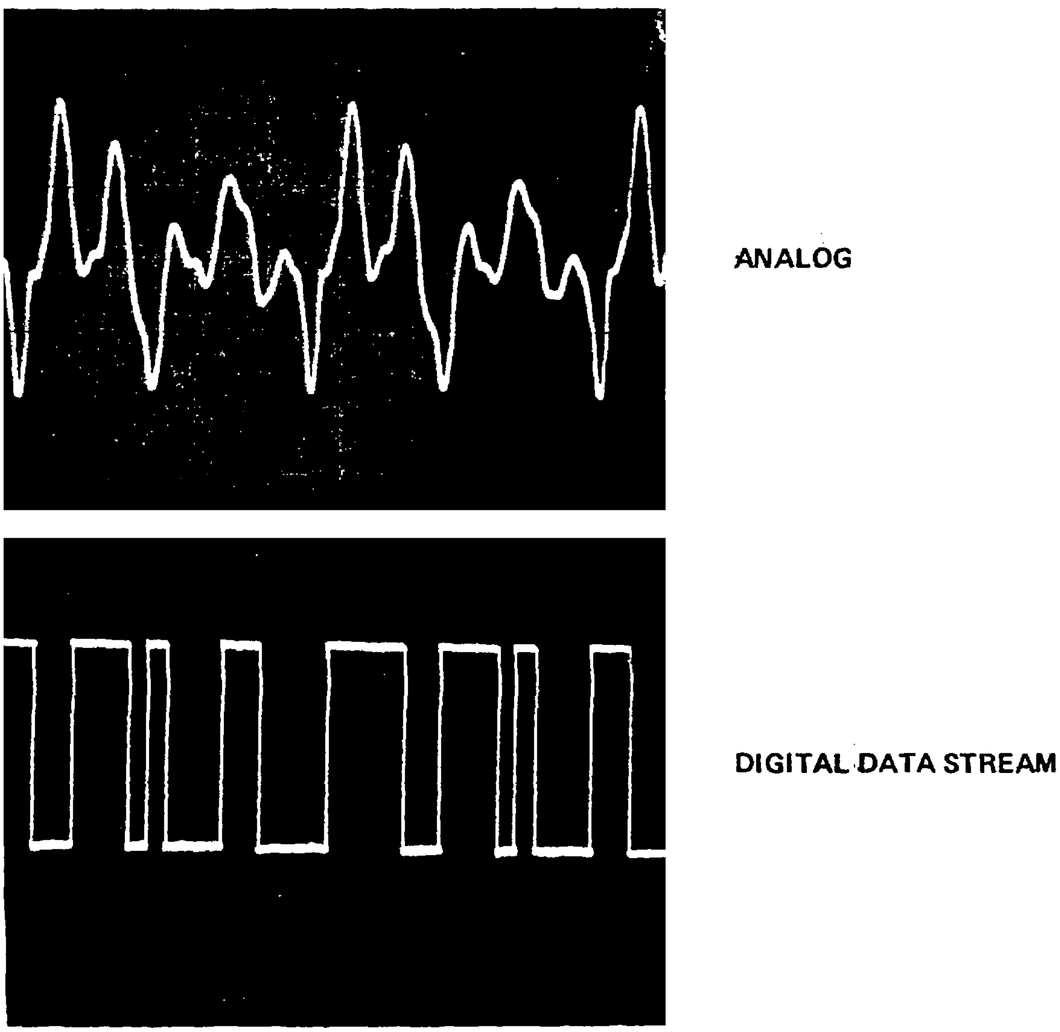


Figure 3-1. Typical analog and digital signals.

b. Analog Signals.

(1) In an analog system. a continuously variable waveform is transferred. Any interference entering the system is added to that waveform. resulting in a composite of both the desired analog signal and the interfering signal: this is shown in figure 3-2. As the level of the interfering signal increases. the amount of degradation in system performance encountered can .be gradual and the overall system performance will depend upon the types of interfering signals. the interference mechanism, and the relative levels of the desired and interfering signals.

(2) Since both the desired and interfering signals are present in the system output signal, the output signal can be monitored with an oscilloscope or other appropriate display device to indicate the presence and type of interference being experienced. 'With proper equipment and experience, an operator can usually identify the type of interference (noise, digital. radar, jammer, etc.) and thus determine the nature of the problem.

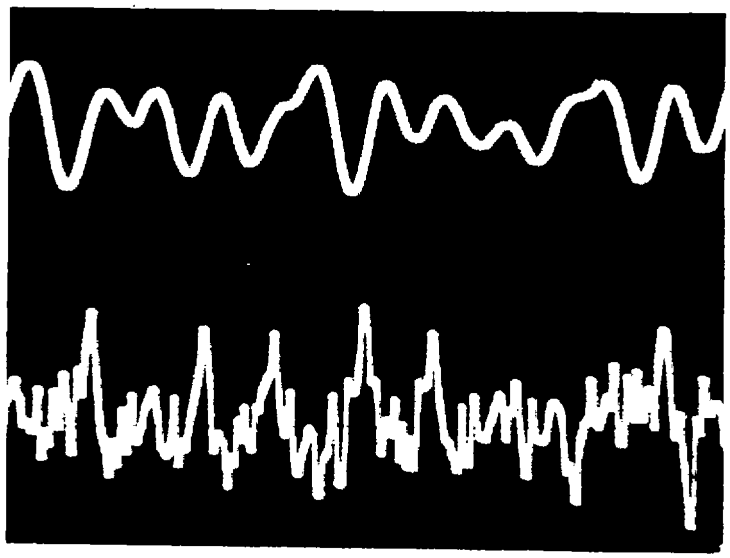


Figure 3-2. Example of analog signal with random noise interference.

c. Digital Signals.

(1) Digital communications systems do not transmit an actual analog input signal. Instead, the initial signal is transmitted digitally. For example, the analog signal may be sampled at some specific rate and each sample converted to a digital signal representing the amplitude of the analog signal at the time it was sampled. Figure 3-3 shows a binary digital signal consisting of "ones" and "zeros." This digital signal is transmitted to the receiver where it is detected and converted back to the original analog form. Interference is not additive as in the analog case, but changes the relationship of the "ones" and "zeros" for the particular sample; this is shown in figure 3-4. Therefore, the interference does not appear directly in the output signal but causes a change in the amplitude or some other characteristics of the reconstructed analog signal for the particular sample or samples.

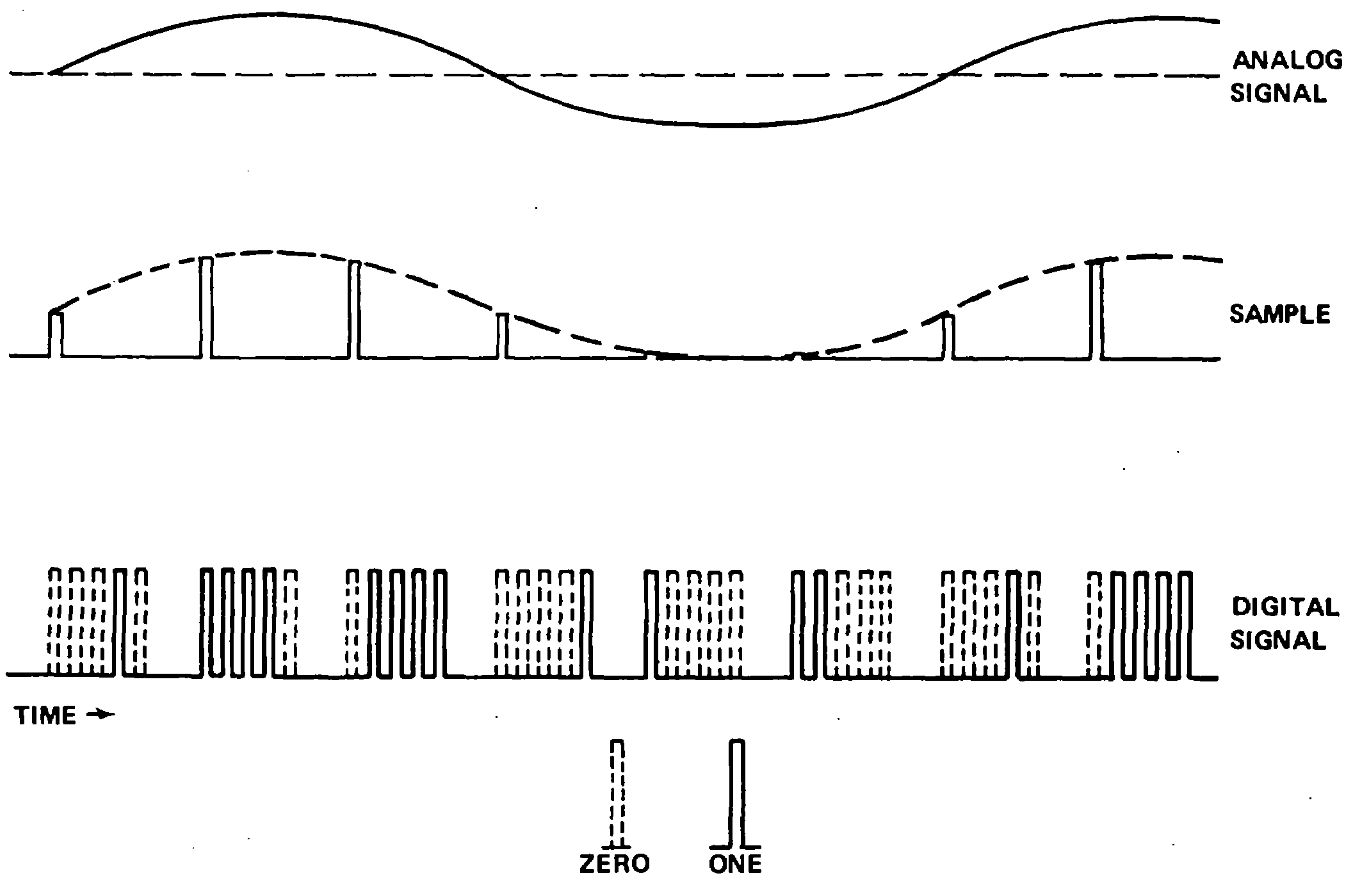


Figure 3-3. Conversion of analog to digital signals.

(2) Since interference in a digital system causes errors in the digital bit stream, some method of error detection can be used to monitor system 'performance. If adequate error correction cannot be provided, retransmission must be requested, either automatically or manually. In a voice channel these errors can cause a change in one or more words with little indication that interference is present. In a data channel, erroneous data is the result.

(3) Most digital systems require some type of time synchronization between the encoder at the transmitting end and the decoder at the receiving end. The susceptibility of this synchronization system to interference is a major factor in the error rate the system can tolerate without total loss of information transfer.

(4) Since the interference does not appear directly in the audio channel output, the output will not provide reliable information for interference identification. However, the total or composite signal is generally present in some form at the receiver detector. Therefore, by monitoring this composite signal prior to pulse detection and restoration. an appropriate display could be used to detect and identify interference in a manner similar to that used in an analog system.

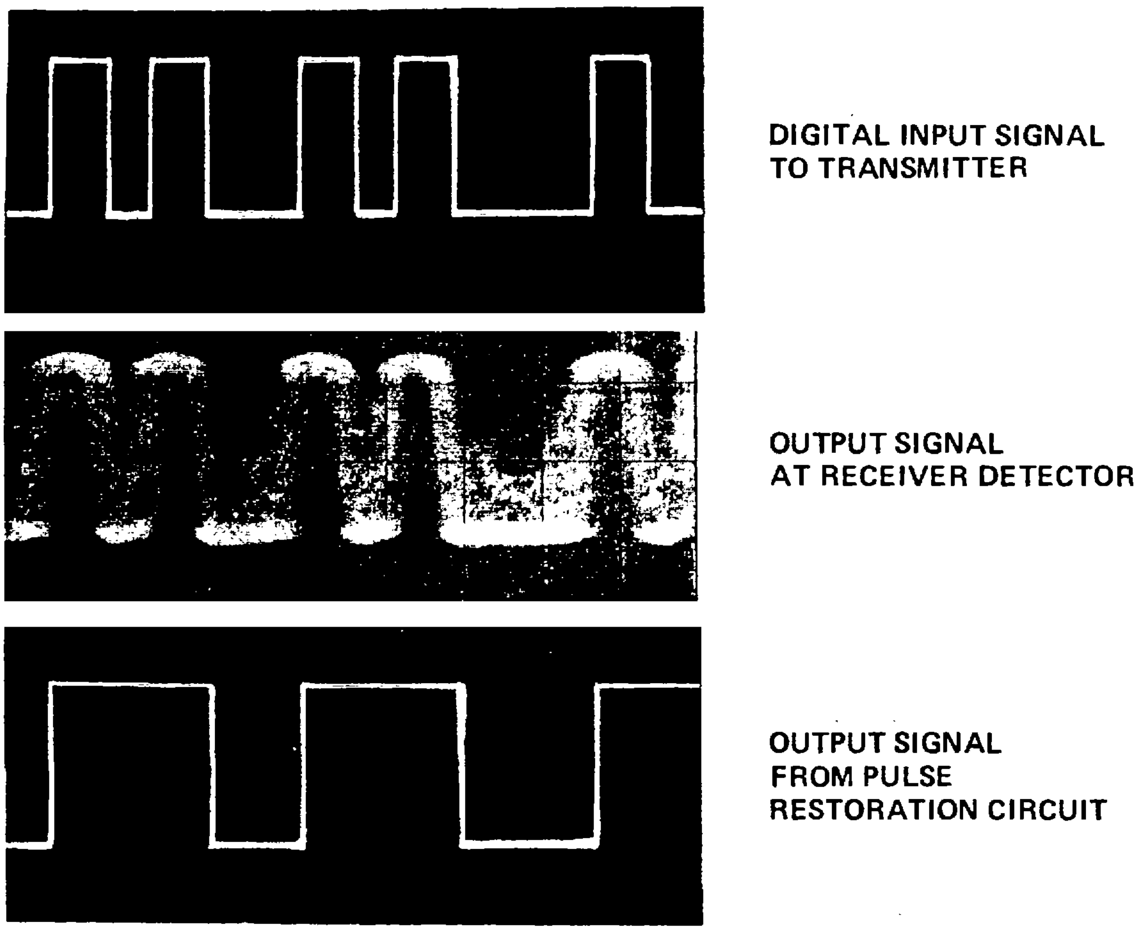


Figure 3-4. Example of digital .signal with interference.

d. Multiplexing Techniques. In order to transfer multiple audio channels over a single radio link, a method of combining or multiplexing the individual channels into one transmitted signal and separating or de-multiplexing the channels at the receiver must be used. The two most common techniques employed in military communications are frequency division multiplex (FDM) and time division multiplex (TDM) (fig 3-5). While FDM is currently the prime technique for multiplexing, there is a trend toward increasing use of TDM.

(1) Frequency division multiplex. In an FDM system the audio channels are assigned to discrete frequency bands just wide enough for the audio signal being transferred. The total frequency bandwidth is the sum of the total number of frequency bands desired. This signal is then transferred over a single transmitter-receiver link. At the receiver, the overall signal is detected and the discrete frequency bands are separated for transfer over individual audio channels. Depending on the intensity and frequency characteristics of the interfering signal, only a few channels may be affected or the whole system may be adversely affected.

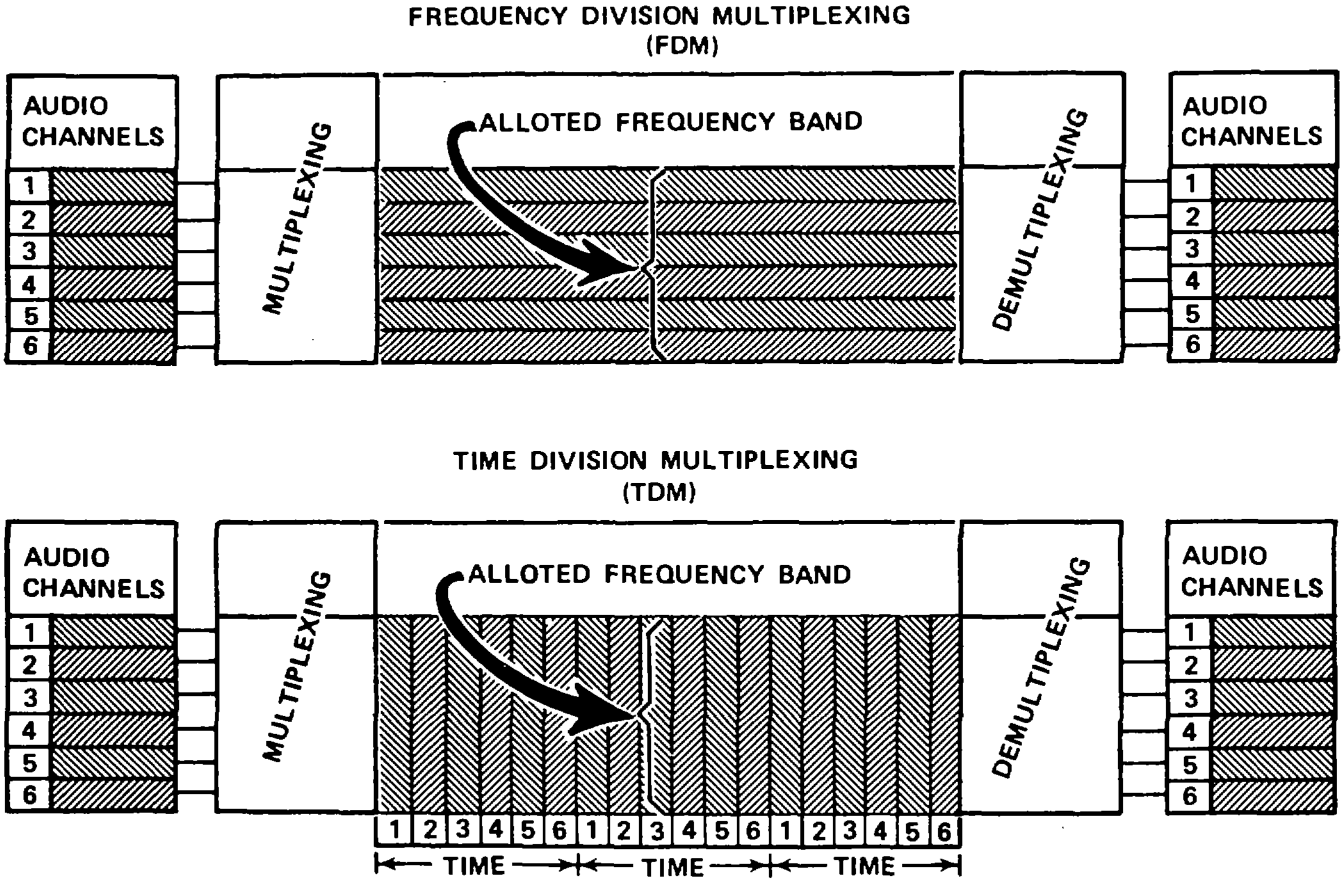


Figure 3-5. Examples of channel distribution for FDM and TDM.

(2) *Time division multiplex*.

(*a*) In a TDM system each audio channel is assigned a discrete time slot. Since TDM systems are digital in form, the characteristics and sequencing of the time slots are determined by the analog-to-digital conversion system employed and the number and nature of the audio channels being multiplexed. In the case of current tactical pulse code modulation (PCM) systems, the sample rate for the analog-to-digital conversion is 8,000 samples per second. Since 6 bits are allocated to each sample, a total of 48,000 bits per second (48 kb/s) are allocated for each audio channel. Channel separation is related to time rather than frequency. Therefore, a method of scynchronizing and maintaining the time relationship of the transmitted and received signal is required.

(*b*) Because the channel separation is a function of time, the information on each channel is transmitted on the total RF bandwidth of the transmitter instead of on a discrete frequency. Therefore, a narrowband, continuous-wave interferer would affect every audio channel in the same manner. A random pulse interferer would also interfere with all channels equally. A pulse interferer operating at the synchronizing frequency of the system could theoretically interfere with one channel only; however, this occurrence is improbable.

(3) *Multiple multiplex*. Both types of multiplexing systems can be double multiplexed. That is, a small group of audio channels can be multiplexed and then combined or remultiplexed with other small groups of audio channels into a large group of multiplexed channels for transmission over the RF link. This approach enables small groups of channels to be extracted from the larger group at an intermediate communications site in a multiple relay system for local distribution, and other local channels reinserted in the larger group without disturbing or demultiplexing the total number of channels being transferred. This does not change the interference mechanism itself, except that it is theoretically possible to isolate and jam one of the small groups of an FDM system.

CHAPTER 4

DETECTION, RECOGNITION, ISOLATION, AND

REMEDY OF EMC PROBLEMS

4-1. General

a. EMC problems at fixed Defense Communications System (DCS) installations or at fixed or transportable non-DCS facilities may be grouped into two broad categories:

(1) Instrasite EMC problems associated with the equipments and installation which generally require some type of maintenance to resolve.

(2) Intersite EMC problems when the interference originates at some location other than the communications site.

b. A DCS station is a vital link in a chain of communications which may provide service between local subscribers or between far-distant points and local subscribers, and may interface with non-DCS facilities. The station .may handle clear-text or encrypted transmissions. The stations may be connected by radio propagation media only, or in combination with cable circuits. However, with the exception of unattended relays, stations are manned by operating personnel who are vital in maintaining successful communications when interference is experienced. At most stations, some incidence of EMC problems may be anticipated. These problems may originate at some location not associated with the communications site, they may be the result of enemy actions, or they may originate within a station. When new equipment is procured, extensive EMC tests are made in an effort to eliminate EMC problems. However, these tests do not always reproduce all conditions in an actual installation. During acceptance tests of a new installation, it may not always be possible to make a complete test covering the entire frequency range which is to be used in operation. As they age, components drift out of tolerance and sometimes fail completely; when this happens, rapid action must be taken to isolate, locate, and repair or replace the component. The human factor is thus of vital importance in the solution of EMC problems.

c. To facilitate rapid solution of EMC problems, operation personnel must be familiar with all facets of their station. They must understand its scope and capabilities, be familiar with normal indicator readings (as they usually provide the first indication of any problems), and be conversant with the use of available equipment. Operating personnel must also learn to recognize situations which require more skilled assistance and to report promptly any problem outside their experience. The following list, although not exhaustive, contains some of the "tools" available to operating personnel:

(1) Test equipment.

(2) Testing and isolation procedures.

(3) Equipment alignment procedures.

(4) Backup or spare equipment and modules.

(5) Patching and rerouting techniques.

(6) Interpretation of equipment meters and indicators.

(7) Antenna orientation.

(8) Communication training.

(9) Substitution.

(10) Signal tracing.

(12) Experience of senior operating personnel.

(13) Equipment history (log books and the like).

4-2. Discussion of EMC Problems

a. Introduction.

(1) When a communications site is installed, intrasite conducted emission problems have normally been reduced to acceptable levels by proper grounding, equipment location, and similar installation procedures. However, normal deterioration will occur over a period of time, corrosion may form on grounds and other terminals, connections may develop higher resistances than normal, and components may degenerate or fail without causing an apparent equipment malfunction. All of these conditions may cause interference. These interference problems can normally be avoided or minimized by proper preventive maintenance procedures.

(2) One major cause of operational EMC problems is radiated signals from sources beyond the local C-E site. This type of intersite interference is difficult to isolate or minimize. It may be unintentional interference from friendly (or enemy) radio or radar transmitters, or it may be intentional jamming or intrusion.

(3) Although interference may originate from an RF source, it usually manifests itself as a faulty operating condition in a subscriber's instrument. It

may first be reported by the subscriber, or be discovered during routine circuit checks.

b. DCS (Fixed Installation).

(1) In the case of a fixed DCS system, the equipment is normally installed in accordance with I)('A standards and other installation criteria. Any deviation from these standards is corrected or a waiver is recorded when the system is accepted and placed in service. Daily logs concerning equipment performance are maintained and a history of any discrepancies and corrective action taken are recorded. Therefore, operating personnal at a DCS fixed site have both the standard performance criteria for the particular equipment and the past history of the performance of the facility. If operating personel are cognizant of the past performance of the system, as recorded in the station log, they can readily recognize any deviation from normal performance. The data also provide information on whether the problem is a recurring one and what corrective action was previously taken. The data may also assist in the isolation of the problem and a determination of whether it is an EMC problem or equipment malfunction.

(2) Intrasite EMC problems can often be traced to a lack of adequate preventive maintenance which can result is partial or complete failure of components. either causing electromagnetic interference (EMI) or increasing EMI vulnerability. The usual cause of loose connections. poor ground connections, corroded terminals. cold solder joints, and faulty cables is lack of proper maintenance. It is worth noting that the installation of new equipment with accompanying cables and jumpers can be the cause of EMC problems not previously present. Existing cables not associated with the new installation can be relocated or damaged to the degree where interference occurs. All new installations or replacement work should be checked for their effects on other circuits.

(3) Intersite unintentional interference at a DCS fixed site is generally caused by installation or operation of new equipment, new frequency assignments, or weather conditions. This results in a site becoming more vulnerable because of physical changes at the site (such as grounding) or abnormal propagation (such as ducting). Frequently, when this occurs, the interfering source may be identifiable from frequency assignments. However, if the interfering frequency is assigned to the intefering station, and the latter is operating within authorized bandwidth, mode, and emitted power limits, the solution will lie in obtaining a different frequency assignment for one station or the other. If this is not possible, steps must be taken to minimize the degree of coupling (for example, slight rotation of receive antenna; use of a more highly selective receiver, if available; or use of a frequency-synthesized receiver instead of the automatic frequency control type, providing the distant wanted transmitter is also frequency-synthesized).

c. Non-DCS (Transportable).

(1) In the case of non-DCS transportable or mobile systems, each time the equipment is moved and reinstalled, new problems may be experienced. Although general performance criteria are available for both equipments and systems, performance at individual locations will vary. Equipment logs can provide some insight into past performance of the equipment and are useful in establishing performance criteria. However, the experience of the personnel assigned to the system as to normal performance under similar geographic, soil (ground considerations), and distance conditions is the most significant factor in the recognition and isolation of an EMC problem.

(2) Intrasite EMC problems at a non-DCS transportable or mobile site are more prevalent than a fixed site, because equipments are subject to movement and reinstallation, and therefore cables and connectors experience greater wear and breakage. Each new installation has a potential for problems with connectors, terminals, antennas, primary power, grounding, and interconnections. The methodology for isolation and location of these types of EMC problems is similar to the fixed site, but the probability of occurrence is much greater.

(3) The source of intersite unintentional interference at a non-DCS transportable or mobile site is also more difficult to isolate and locate than at a fixed site. Since the system is the new element in the area. the number and location of potential interferers in the area are unknown unless an extensive site survey and frequency monitoring have first been performed.

d. Unintentional EMC Versus Intentional ECM Problems.

(1) When outside interference is detected, the operator must determine whether the problem is attributable to unintentional causes or whether jamming or intentional intrusion is occurring. Where the latter is suspected, any action taken must be such as to deny the enemy any intelligence regarding the effectiveness of his actions, or the fact that they have been detected.

(2) The procedures for dealing with enemy action are prescribed by AR 105-3, "Reporting Meaconing, Intrusion, Jamming, and Interference (MIJI) of Electromagnetic Systems;" AR 105-87, "Electronic Warfare;" and DCAC-310-70-6, "Jamming or Sabotage of DCS Telecommunications Facilities."

4-3. Recognition, Isolation, and Remedy of EMC Problems

a. Introduction.

(1) The most important factors in resolving EMC problems are the knowledge operators have of their stations and the ability to speedily detect any operational abnormalities. A knowledge of normal meter and indicator readings, signal "sounds" at audio frequency, and visual representation of signals on a cathode ray oscilloscope display or spectrum analyzer are all good tools in detecting abnormalities and effecting rapid corrective action. This should be coupled with a thorough familiarity with all aspects of station configuration. The station log, together with performance records for channels and systems, is an invaluable record of problems and their causes. Use of these logs may facilitate and even expedite resolution of EMC problems. A thorough knowledge of routine maintenance checks will facilitate the development of procedures designed to remedy abnormalities causes by EMC problems.

(2) An interference problem can be isolated to a particular element or equipment within a communications site by signal tracing, if adequate equipment monitoring or test instruments are available, or by substitution when instrumentation is limited. However, in some cases, it can be extremely difficult to determine precisely at what point (component, subsystem, or system) interference is being introduced. Frequently, resolution of a problem is achieved not by a study of what is affected, but rather on determination of the source and the coupling medium, then controlling, reducing, or eliminating either the source or the coupling medium. In any case, the important factor is to proceed methodically rather than skip from equipment to equipment in a random manner. For instance, if trouble shows up on a channel, and it has been determined that the transmitting station is not at fault. the trouble could lie within circuit modules at the channel level, such as line amplifiers; in channel, group, and supergroup demultiplexer circuits: in baseband amplifier modules; within the receiver; or at the antenna. Probing of these circuits, in this order, at the system test jacks and use of appropriate test equipment should isolate the problem. Substitution, in the event that test equipment is not available, involves the placing in service of alternate channels, modules, and equipments by means of patching and special cabling, if necessary in emergencies. The substitution method, although effective in isolating interference to a particular equipment or its associated cabling, is generally slow and has the disadvantage of requiring interruption of service during substitution, unless parallel circuits can be used to advantage without disturbing normal operations. If available at the site, a battery powered multiband radio becomes an. effective diagnostic tool providing aural indications which, when used in conjunction with an improvised directional antenna, can aid in determining the direction of the interference source. Aural indications can often be correlated to aural noise at a patch panel or output of equipment. If a frequency is noted, at which the type of interference is heard, the radio should be taken outside of the area or away from the shielding influence of equipment so that an attempt can be made to identify the source of EMI. If the EMI is weaker outside, the radio should be brought inside as the source is probably in the building. An improvised loop antenna used with either the radio or a frequency selective voltmeter may be used to determine the direction of the EMI source or to make a specific determination of the generating equipments and leads carrying the noise. It may be necessary to obtain the assistance of maintenance personnel in fabrication of a suitable loop antenna. Being battery-powered, and therefore free of the station's primary power source, the radio can be used to determine whether the interference is entering the system by RF radiation or through the primary power lines. Poor grounds, cracked or dirty insulators, or defective transformers in the ac power system can, under certain conditions, be located by moving the radio closer to the suspected interference source.

b. Recognition Procedure.

(1) Determine origin of the interference.

(*a*)The effective clearance of a suspected EMC problem requires a rapid initial assessment of the origin of the interference. That is, was it generated within the local station, or was it generated by a distant station? In the latter case, the source must be determined. To allow effective application of isolation procedures (para 4-3c) this determination must be made without delay.

(*b*) Although interference can be introduced into a station from an external source by means of cables and transmission lines, the most common avenue of entry in systems employing radio equipment is through antenna/receiver systems. Although interfering RF emissions may be locally generated, the majority are caused by distant transmitting stations. Steps which can be taken to determine whether the interference is entering the system by RF means are as follows:

1. Check whether the signal level has increased significantly at the receiver output. If it has, this may indicate an interfering signal on or close to the receive frequency.

2. Display the output on a spectrum

analyzer, if available, to see how it compares with a normal receive signal.

3. If necessary, have the distant desired transmission disabled, to allow a better visual and aural examination of the receiver output to see whether cochannel interference is occurring.

4. If necessary, change the receiver antenna and/or alter the antenna azimuth slightly (if practicable) to observe any effects on the extent of the interference.

5. If the above steps are inconclusive, disconnect the receiver antenna from the receiver and connect in its place the carrier output of a suitable signal generator adjusted to the receive frequency, at an appropriate level. (If the receiver has a beat frequency oscillator, it should be disabled.)

6. Apply a suitable degree of modulation to the signal generator and observe the receiver output. This is to ensure that the receiver is not introducing any interference due to nonlinearity.)

7. The next step is to arrange an RF "back to back" test, keeping the receiver isolated from its antenna, as follows:

(*a*) Retain the connection from the signal generator to the receiver input, but switch off the modulation.

(*b*) Connect the composite transmit output of a multiplex/submultiplex system to the "external modulation" -jacks or terminals of the signal generator. (Insure that the depth of modulation is such as to provide linear operation.

(*c*) Provide keying on the channels which were suffering interference.

(*d*) Adjust the receiver output to normal receive multiplex/submultiplex system levels. In this way a "back to back" arrangement is achieved which incorporates all receiving equipment except the antenna system. If the interference is still present, it originated within the station. If it is no longer present, it was introduced by RF means. Remember, however, that it could be originating at the desired distant station due to a fault condition there.

(*c*) In making the above determination, it must be remembered that even if interference is introduced by RF means, it could be locally generated. However, the determination greatly facilitates isolation procedures.

(*d*) If the interference is entering the system by RF means, a check must be made to establish the source. Cochannel interference might require the distant wanted station to disable its transmitter output to allow the local station to demodulate and print (if possible) the interfering signal as a means of identification. Adjacent channel interference is more easily discernible and is usually easy to see on a spectrum analyzer or oscilloscope. A portable radio or high impedance earphones are also useful tools for an experienced operator to determine the presence and nature of RF interference.

(*e*) If it is determined that cochannel RF interference is present, the possibility of deliberate interference or jamming by unfriendly forces must be investigated.

(*f*) If it is suspected that the interference is jamming, do no use the orderwire or any other form of clean-text transmission to advise another station of the severity of the interference, or even that interference is present, until it has been determined that jamming is not involved or the proper authority has been informed and a go-ahead has been obtained.

(*g*) If the interference is not being introduced through the RF medium, rapid isolation: , to either baseband (audio) or the multiplex carrier will assist in recognition of the type of interference. If the interference was introduced into the baseband audio signal or the multiplex system prior to transmission, it may be difficult to recognize at the receiver unless the operator has experienced this type of interference previously. Therefore, the origin of the interference to either the baseband audio or multiplex system can normally be traced more rapidly by checking the multiplex system at both receiver and transmitter sites. Detailed procedures for isolating the entry point into the system are contained in (2) below; however, a check of the input and output signals of the multiplex equipments can provide a rapid determination of the multiplex performance. If this performance is determined to be normal, then further isolation to cabling and switching circuits as detailed in c (3) (a) and c (3) (b) below may be required.

(2) Determine nature of interference.

(a) Monitor the channel or channels in question with high impedance earphones or other available test equipment to determine the nature of the interference. Table 4-1 provides a listing of the audible output to be expected from a receiver under various interference conditions and may be used to assist in the recognition of interference sources. Note that the conditions listed in this table will be in addition to the signal normally heard, which itself may be in the form of tones, recognizable to experienced operating personnel, but from which it is impossible to extract the intelligence of the signal by merely listening. That is, other end instrumentation would be required for signals such as teletype, digital, and facsimile, in order that the manner in which the intelligence of these signals is affected can be determined. As an alternative, the desired signal could be disconnected at the far station so that the interference alone could be heard. Figure 4-1 shows

the effect on an audio signal of some of the terferers listed in table 4-1.

Table 4-1. Audio Output Responses Characteristic of Various Types of Interference

Receiver audible output	Character of interference	Possible source or mechanism
Reduced noise level (or steady tone with beat frequency oscillator (BFO) operating)	Carrier (only)	Cochannel, spurious, intermodulation
Pulsed variation in noise level (or pulsed tone with BFO operating)	Pulsed continuous wave (CW) or digital transmission	Adjacent channel, co-channel, spurious, intermodulation, cross modulation
Pulsed variation in noise level (two pulsed tones with BFO operating)	Unwanted radio teletypewriter (RATT) frequency shift keying (FSK) transmission	Adjacent channel, co-channel, spurious, intermodulation, cross modulation
Added normal or distorted voice	Unwanted voice transmission	Adjacent channel, co-channel, spurious, intermodulation, cross modulation
Whistling or squealing	Unwanted transmission or intermediate frequency oscillation	Adjacent channel, co-channel, spurious, intermodulation, cross modulation, parasitic and IF oscillation
Rapid variation in noise level (or several pulsed tones with BFO operating)	Unwanted facsimile transmission	Adjacent channel, co-channel, spurious, intermodulation, cross modulation
Steady tone or whining	High rate periodic pulses	Radar, rotating machines
Buzzing	Medium rate periodic pulses	Buzzers, vibrators
Popping	Low rate periodic pulses	Ignition systems, magnetos
Hum	Low (60 Hz) rate	Power lines
Frying	High rate random pulses	Electric arcs, continuously arcing contacts
Sputtering	High rate random pulses	Arc welders, arc lamps, diathermy
Clicking	Low rate random pulses	Code machines, electric calculating machines, mercury arc rectifiers, relays, switches, teletypewriters, thermostatic controls, electric typewriters
Crackling		Static or corona discharges
Sharp crackle		Ambient noise

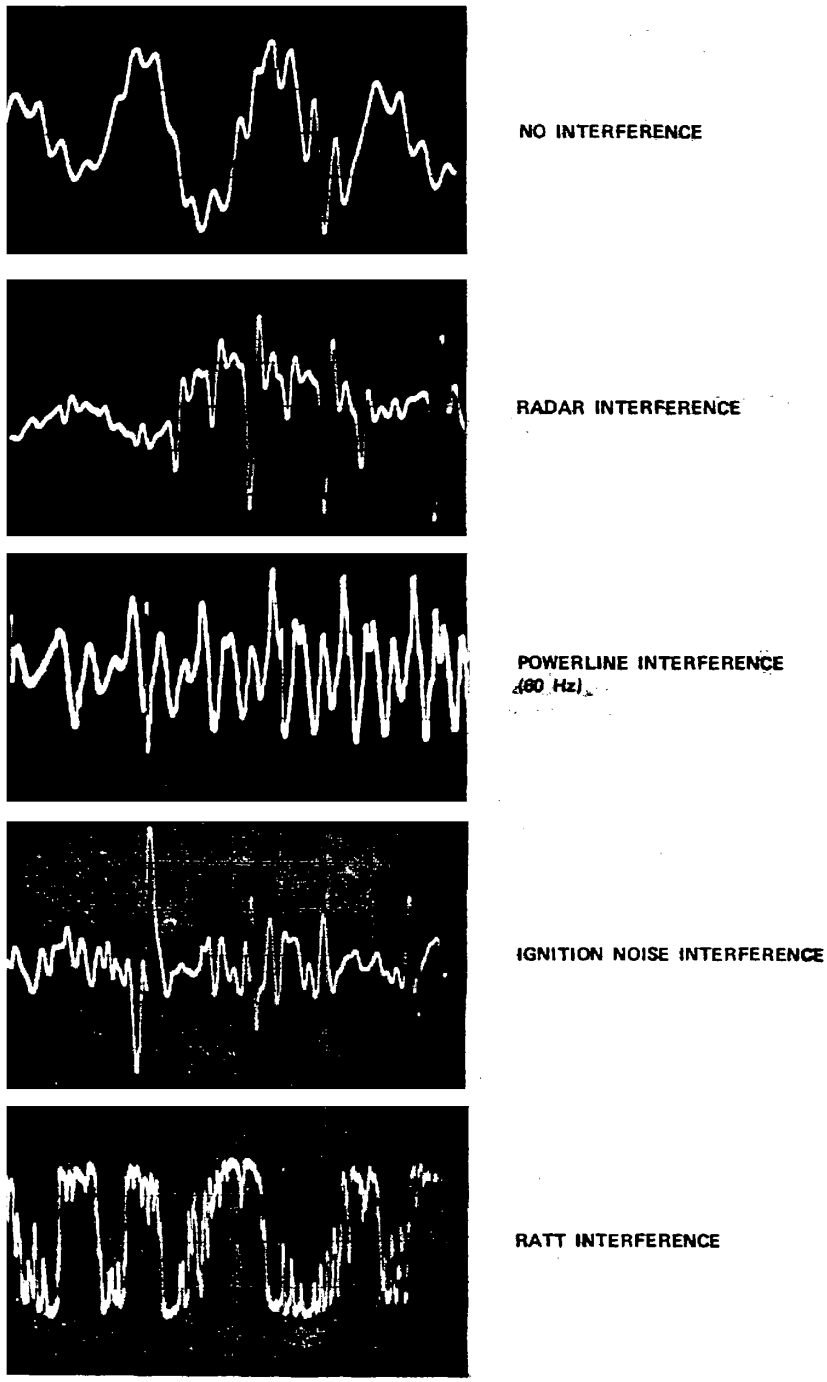


Figure 4-1. Audio signals subjected to various interference effects.

(*b*) The following 1. through 6. contain information regarding the effects that various types of interference have upon communication systems. The purpose of this information is to assist in the detection and recognition of the interference source. Table 4-1 contains audio output response characteristics in a condensed form which can be used in recognition procedures. These specific recognition

procedures are pertinent to both DCS and non-DCS facilities.

1. Ignition noise. Privately owned vehicles in the vicinity of a communications site normally do not contain extensive noise suppression devices and are therefore sources of ignition noise. The noise is characterized by a popping sound at a low periodic rate which varies with the speed of the engine. Gasoline-powered lawn mowers are also potential noise sources around communications sites. Ignition noise from these machines results in high levels of radiated emissions because of their relatively open construction and consequent lack of shielding. The level of interference will vary, depending on the type of signal being received. For example, since ignition noise has a rather broad RF spectrum, it will usually affect all channels of an FDM system. In the case of PCM, which is time dependent, the number of channels affected would depend on those channels which were in the time slot when the interference pulses occurred. At low operating speeds, the interference pulses occurred. At low operating speeds, the interference may appear to be random popping on a single channel. At high operating speeds, however, the PCM system may be totally affected.

2. Radar. A pulse-modulated radar can cause broadband interference similar to vehicular ignition noise; however, the periodic rate is directly related to the PRF of the radar. If aural means (earphones) are used to monitor this type of interference, it will be noticeable as a definite and recognizable tone, as opposed to the popping characteristic of ignition noise. The intensity of the interference will also vary as the radar antenna rotates, if the radar is a scanning type. The visual indication will be that of a pulse moving across the oscilloscope display (fig 4-1).

3. Office equipment. If offices are colocated with the communications site, office equipment, especially calculators and data processing equipment, present a potential interference problem. The interference will be manifested as a random rate clicking sound which affects most types of signal modulation. Improper filtering and poor grounding are common causes for this interference affecting communications equipment.

4. Power lines. Power lines are a potential source of many interference problems as a result of insulator and transformer breakdown, poor ground connections, lightning discharge transients, and feedback interference from equipment using a common power source. The interference may be in the form of a 60-Hz hum, as in the case of poor ground connections, or poor earth grounding at the power pole; frying sounds as when transformer breakdown occurs. or insulators become damaged; or high-pitched whine from rotating machines.

5. Cables. Interference problems attributable to cables may result from damage which has caused insulation breakdown, or breaks in shields. Interference may be noted as hum which results from broken shielding, improper shielding, or improper shield connections; or crosstalk as a result of signal-carrying pairs being in proximity, particularly when high signal levels are carried in proximity to low signal levels as when improper cabling, patching, or jumpering for a given installation task occur.

6. Equipment grounding. Defective or improperly installed earth grounds and equipment grounding systems are a major source of EMI problems. Primarily, the cause is an unwanted resistance common to one or more circuits as a result of ground paths longer than necessary or poor ground connections. These conditions are more frequently encountered in multiple ground point systems rather than common point systems. The indications that grounding insufficiencies are the origin of EMI are varied and dependent upon the circuit involved; however, the usual symptom is powerline hum. In other instances, the problems may be simply that equipment malfunctions occur because of high impedance return paths which limit current flow and cause reduced operating voltages.

(3) *Identification of possible jamming sources.* Jamming stations use various types of emission/modulation. When such interference is encountered, the possibility of jamming must be considered. Methods of jamming typically employed are as follows:

(*a*) *White noise*. So-called "white" noise derives its name from its counterpart in the optical spectrum, white light, which results from all frequencies in the visible spectrum. Likewise, white noise consists of many radio frequencies combined whose energy content is relatively constant per unit bandwith across the RF spectrum. Figure 4-2 contains oscilloscope traces which show the effect of white noise interference on an analog signal for the conditions of the signal much greater than the interference, the signal slightly greater than the interference, and the interference much greater than the signal. Characteristically, white noise interference at levels equal to or greater than the desired signal would completely block out any audio signal with a continuous hissing sound. This type of noise is normally associated with jammers; however, when it occurs, the possibility of other problems, such as when semiconductors degenerate, should not be ruled out. At levels much less than the desired signal, white noise affects the signal as a background hiss. White noise at considerably less amplitude than the signal could point to circuit problems also and would not normally be indicative of jamming.

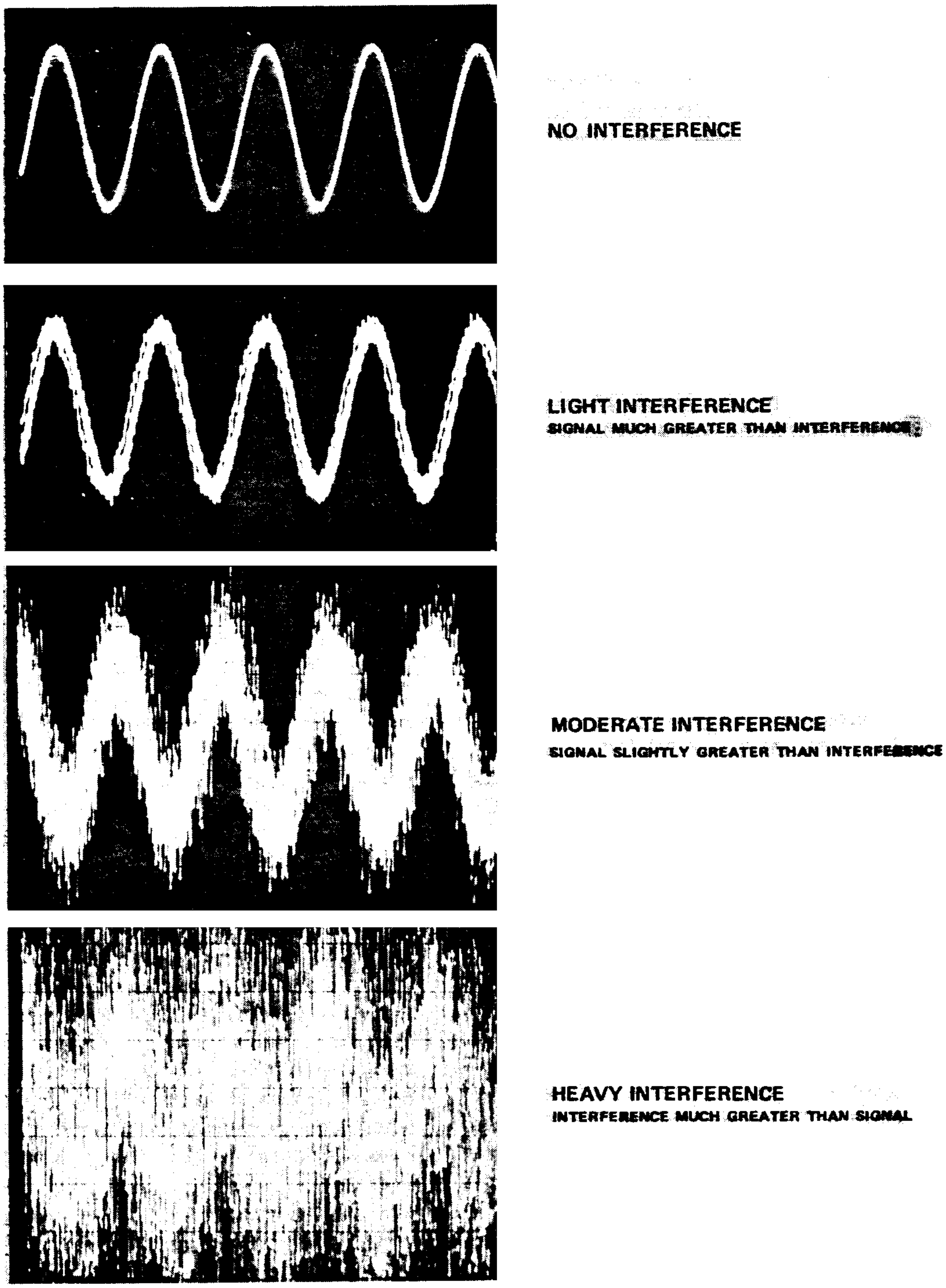


Figure 4-2. Examples of oscilloscope traces of I kHz test tone signal to white noise interference levels.

(b) Random noise. An oscilloscope tracing of this type of interference, which is similar to white noise, is shown in figure 4-3. At a jamming station, the noise is originated from the modulation of a jamming transmitter by a random noise generator. While not "white" in the sense that the energy is not as evenly distributed throughout the electromagnetic spectrum as white noise, the effect is much the same. The effect shown in figure 4-3 is that of random noise at approximately the same power level as the analog signal and would be heard as a hissing sound completely blocking out the signal.

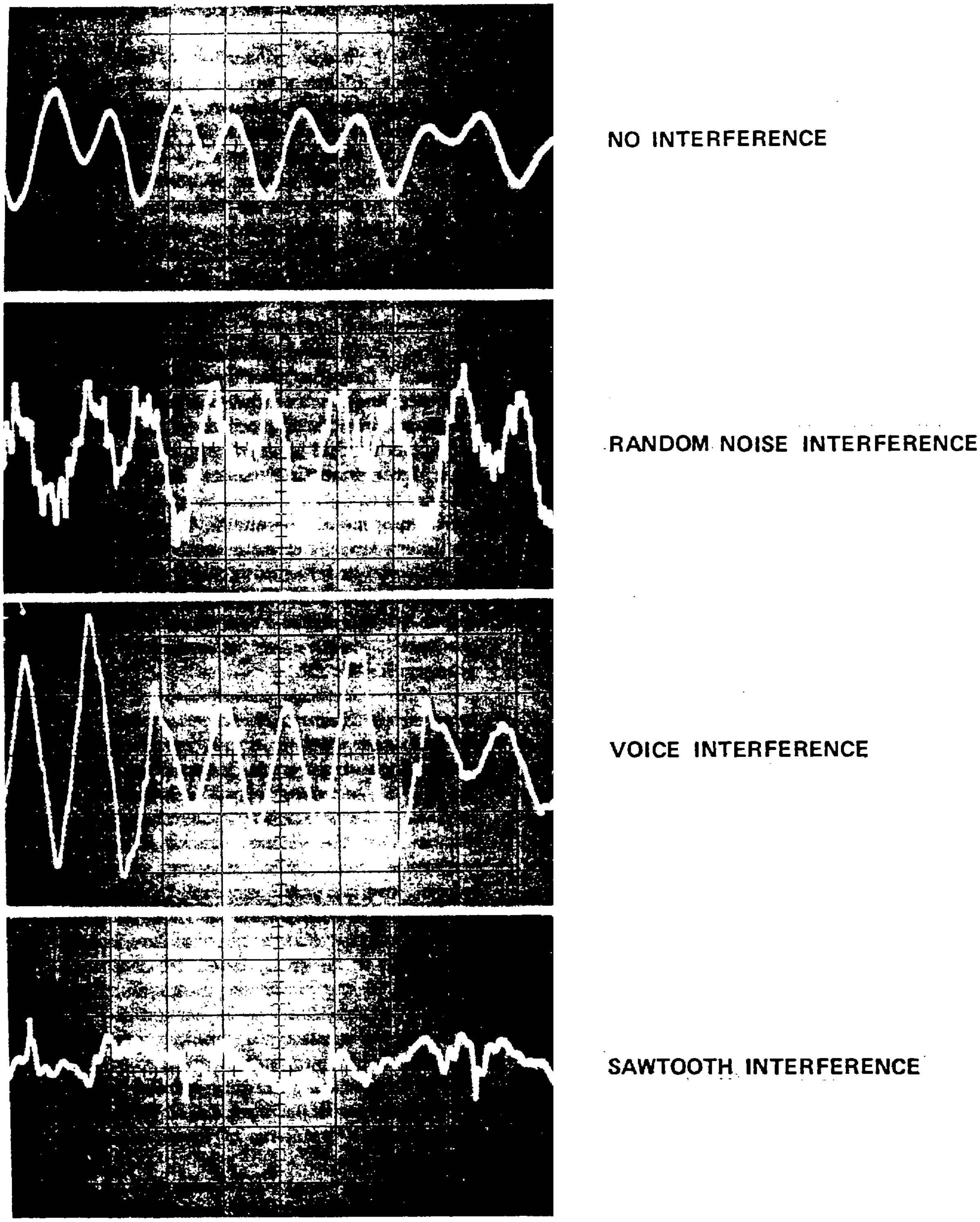


Figure 4-3. Examples of oscilloscope traces of an analog signal with various types of interference.

(*c*) *Sawtooth*. A sawtooth waveform is frequently used to modulate a jammer. Figure 4--3 depicts one example of interference causes by a sawtooth waveform. It is unlikely that this type of interference would be associated with any other cause than jamming. This interference would be heard as a periodically occurring chirping sould which obliterates signal intelligence.

(*d*) Voice. Voice interference can occur, of course, as a result of crosstalk, or from other transmissions; however, there is a possibility of the interference being the result of a voice-modulated jammer. Figure 4-3 shows the oscilloscope display as a result of such a jammer signal interjected with an AM signal. The sound of such a signal at the receiver output would be that of two signals being heard at the same time. If the signal is strong and no known friendly station is nearby, jamming should be suspected. If the interfering signal is weak, fades irregularly, or occurs only at a certain time of day, it is more likely the result of ionospheric refraction from a distant transmitter (HF and low end of VHF). Any interfering signal, digital or voice modulated, should be compared with normal traffic through the station. Friendly interference commonly encountered should also be compared.

(4) If jamming is suspected.

(a) Determine frequency of the interference. Use a spare receiver connected to a separate antenna. or a battery powered multiband radio to determine whether the interference is tunable; that is, whether the interference appears on the desired signal RF channel only, on adjacent RF channels, or at an image frequency. To determine whether transmissions at an image frequency are responsible, tune the radio above and below the desired signal tuned frequency by an amount equal to twice the IF of the station receiver. The characteristic sound of the interfering signal should increase at one or the other of these settings if the image frequency from another transmitter is involved. If the interference is found to be cochannel with the desired signal, a strong possibility exists that the interference is intentional.

(b) Determine direction of interference. Use a directional antenna in conjunction with the receiver or radio of step a above to identify the direction from which interference is coming. Based on the results of steps a and b, check with the appropriate authority to determine whether a friendly station would normally be operating from that direction and on the frequency encountered.

c. Isolation Procedures. The first step in the isolation of an interference problem is to examine the degree to which the interference has affected the communications system; that is, how many subscribers are reporting problems. Next, the problem must be isolated to a major system, then further isolated to a major component within the system. These procedures are given in this order in the paragraphs that follow.

(1) Isolation based on extent of interference. The following procedures are based on whether one or multiple subscribers being serviced by a particular multiplex equipment are affected by the interference problem.

(a) Single subscriber affected. If the interference affects a single subscriber, the trouble source is likely to be between the subscriber unit and the communications site or the appropriate patching facility at the site. However, a single-channel fault could also be the source of interference. A typical isolation procedure is as follows:

1. If the link to the subscriber is by cable, first substitute spare subscriber equipment, including security devices. If interference is still present, check the cable in accordance with paragraph 4-3c (3) (b).

2. If the subscriber is linked by radio, the output of the subscriber's receiver must be checked to determine whether the problem originates within or external to the subscriber station. If the receiver output is normal (correct signal content and level) then interconnecting cables and end-instruments may be faulty. Noise must be checked, substituting spare equipment, if available, to maintain service. If the interference is introducted by RF means (para 43b (1)) and no interfering station can be discerned, steps must be taken to determine whether a fault exists in the distant transmission. Check in accordance with the procedures described in paragraph 4-3c (2).

(b) Multiple subscribers affected. If the interference affects multiple subscribers, checks will depend upon whether or not interference is present on the incoming signal. Isolate as follows:

1. Incoming signal interference free. If a problem affects various subscribers of the local station. and the distant station has checked and confirmed that their outgoing transmission is correct. and no other external interference can be detected, the interference is local in origin, most likely occurring within the station demultiplexing equipment at the group level. To determine, check the input to the particular group demultiplexer in question in accordance with paragraph 4-3c (2) (d 1). If the signal is clear, the problem originates in the demultiplexer equipment. If the interference is present. check the preceding patches and terminals in accordance with paragraph 4-3c (3) and also check for the usual problems of loose connections and corrosion.

2. Incoming signal contains interference. If a check of the incoming signal reveals that interference is present, and if the interference affects multiple subscribers, the trouble most likely originates in the RF link with the preceding station or in that station's RF equipment. Consider a typical example where a carrier system employs voice frequency telegraph over a 4-kHz audio channel and

multiple subscribers are reporting problems. To affect rapid isolation of the source of the interference, proceed as follows:

(*a*) On the orderwire circuit, request the distant-operator to check his transmission from the transmit voice frequency telegraph system. This is accomplished through appropriate patching and monitoring and the results are reported. If the report is that clear copy is leaving his station, then the trouble lies either along the propagation path, in antennas and connections, in any interconnecting cables, or within the local operator's own station.

(*b*) Monitor adjacent channels to determine whether they are also affected. If these channels are affected, service may be restored by connecting to available spare channels. Notify the distant operator to do the same, after informing the subscribers that a momentary interruption of service may be necessary while patching is accomplished. Equipment (possibly multiplex) malfunctions are indicated; or if only a few channels are affected, possible EMC problems are involved. If a single channel only was found to be affected, this indicates that other than EMC problems are involved and corrective maintenance must be accomplished.

(*c*) A quick check can be made to determine whether a carrier channel is at fault by reconnecting the channel at both stations to a spare channel. Care must be taken that such reconnecting is coordinated to avoid undue disruption of service.

(*d*) If connection to spare channels does not restore service, the interference may be caused by a local transmitter or ancillary, or there may be a problem arising from proximity of the transmission line/antenna system to the circuit suffering the interference. In this case, a detailed check of the antenna and transmission line would be required, including measuring the voltage standing wave ratio, unwanted ground connection, corrosion, insulation breakdown, and the like.

(*e*) If problems are still apparent, checks should be made of the RF signal levels throughout the system, back to the originating station. Levels which are too high will usually cause overdrive problems with accompanying nonlinear distortion. Those which are too low cause unnecessary degradation of the signal-to-noise ratio. Adjustments must be made to ensure that levels are correct. Refer to paragraph 4-3d (8).

(*f*) It is possible that the problem could stem from nonlinearities within the voice frequency telegraph terminal, from the carrier system, or within the interconnecting cables. A distortion analyzer may be used to detect nonlinearities in the system.

(*g*) If reconnection to a spare channel fails to clear up the problem, equipment problems, such as receiver alignment or receive module malfunctions are possible. Isolate the trouble by substitution.

(*c*) If a station has been informed that their transmissions are interferring with the receipt of signals by another station, certain steps may be taken at the suspected station to determine whether this is actually the cause of the problem:

1. Obtain approval to take the transmitter off the circuit.

2. Terminate the transmitter into a dummy load, and proceed to check whether transmitter is operating normally as indicated in paragraph 4-3c(2)(b).

(2) Major system isolation procedures. As indicated previously, a major point where interference can enter a communication system is the radio link. This radio link normally consists of a transmitter with some type of modulator, the receiver, the transmit and receive antenna system, and the transfer media between the two antennas.
Although the exact methodology will vary depending upon the equipment and type indicators or test instrumentation available, the procedure is similar for all components.

(*a*) Receiver.

1. With the test instrumentation available, check the receiver output signal to determine if it is normal for the particular system. If the system is transferring digital signals and the pulse recognition and pulse restoration circuits (that is, the circuits that determine when a pulse is present and then generate a true pulse at that time interval) are an integral part of the receiver, the signal should be monitored between the detector and these pulse circuits. If the signal is normal, the interference is not entering through the radio link.

2. If the signal is not normal at the receiver output, the receiver input signal should be checked using available signal indicators, test instrumentation, and test points. If the RF signal cannot be checked, the IF signal can provide an indication of signal level and deviation from normal. A spare receiver or broadband portable radio may also be used to check the incoming RF signal. If the input signal is normal, as determined by tests on the actual receiver, the spare receiver, or the portable radio, the distant transmitted signal is interference free. If not, then the distant transmit system may be at fault. If there is no fault at the distant station and there are no apparent propagation problems, local testing will be required to determine whether the problem is associated with the actual receiver or receiver antenna system. This can most readily be accomplished by replacing the receiver. If the

receiver output is now interference free, the receiver was at fault. If the signal is still not normal the receiver antenna system should be checked. If available, use another receive antenna system on circuit to minimize circuit downtime during testing.

3. The above procedure is closely related to that described in paragraph 4-3b (1) (a), "Determine origin of the interference." Both are examples of similar isolating techniques. There are other variants.

(b) Transmitter. Using the orderwire, operational personnel at the distant transmitter station should be requested to check whether transmitter operation is normal. Generally, transmitter checks are limited to assuring that modulation is normal and at the proper level and that all monitoring indicators and instruments are reading normally (for example, the drive level is correct, the transmitter is on the correct antenna, and VSWR readings are normal). At some stations, spectrum analyzers are available, permitting visual observation of the output signal. A spare receiver or broadband portable radio with proper input attenuation to prevent receiver overload or damage can provide an indication of proper transmitter output, to include the transmitting antenna system. If the transmitter output is normal, the interference problem is associated with the antenna systems or the transfer media.

(c) Antenna.

1. Generally, transmitting antenna problems will be indicated by changes in the readings of the output and loading at the transmitter. Interference problems associated with receiver antennas generally will cause fluctuations in the receiver signal level. However, interference in the incoming RF signal can cause similar indications. Interference problems could arise from nonlinearities in multichannel HF antenna isolation or multicoupler devices.

2. If antenna problems are suspected, another antenna can be substituted, or repair personnel can be requested to make a voltage standing wave ratio -(VSWR) or noise power ratio (NPR) test on the antenna system.

3. If the distant transmitter output and the antenna systems are normal, the interference is entering through the RF medium. A spare receiver or battery operated broadband portable radio with some type of directional antenna is probably the most rapid means of isolating the source, direction, and type of interference. The experience and capability of the operating personnel are most important in the recognition of the type of interference and its probable source. If appropriate monitoring equipment is available, the logical procedure when interference is present in the receiver output would be to first check to determine whether the assigned RF is interference free prior to conducting any further isolation tests.

(d) Multiplex equipment. In simple terms, multiplex equipment combines multiple input signals (normally discrete audio channels) into a composite signal that is used to modulate a transmitter without any interchannel interference and reverses the process at the receiver by converting the composite received signal into multiple channel output signals. To isolate an interference problem to the multiplex equipment, the output and input signals are checked to determine whether they are normal. If the input is normal and the output has interference, the problem is in the multiplex equipment. If the system uses double multiplexing (group and supergroup), composite input/output signals of each of the multiplex elements should be checked in a similar fashion to that described above. Generally, grounding problems or direct external interference affecting a multiplex equipment will interfere with all output channels of the specific multiplex element. If only one output channel has interference, the most probable cause is a component malfunction within the equipment or a misadjusted drive level. Individual channel drive levels are normally very critical on the transmit multiplex. Check to be sure these drive levels are adjusted to specified values. In most communication systems some interference (noise and tines) is usually present. In a well-designed system, it would be usual for interfering noise to be lower in level than the system's intrinsic noise and thus could be ignored. However, if noise levels increase above predetermined levels, action is necessary to determine whether a maintenance problem or an interference problem exists. Up to a point, isolation procedures for both types of problems are identical and along the lines described above. Further information which will assist in isolating the problem is as follows:

1. Type of noise.

(*a*) Whether the noise is wideband or narrowband.

(*b*) The frequency range of the interference.

(*c*) Whether a tone is involved and whether the tone appears in more than one channel.
Also, whether the tone is a modulated frequency of a tone in the channel.

(*d*) Whether the interference is a signal interference such as music, voice, on-off keying.

(*e*) Whether the noise seems to be powerline related.

2. Levels.

(*a*) Whether the receive signal power levels are normal.

(b) Whether the transmit signal power levels are normal.

(c) Whether the correct loading attentuation for the number of channels in operation has been introduced.

3. Stations and systems affected.

(a) Whether similar systems in the station are affected.

(b) Whether similar systems in other stations are affected.

(c) Whether a few stations or many stations are affected.

(d) In the case of dual-redundant systems. the effect of turning "A" side and "B" side off.

(e) Whether the noise is affected by weather: for example, whether it is greater during dry weather.

(f) 'Whether any station reported higher than normal receive levels. In this case, waveducting (a propagation phenomenon) may be involved.

4. Special EMC considerations. Because the frequencies used by the internal processing portion of FDM multiplexing systems fall within the standard AM broadcast band (535-1605 kHz), interference may result when FDM systems are located near a broadcast station. Typically, there are two different types of interference which may be experienced from. broadcast station sources. The first type results when the broadcast station assigned frequency falls in the middle of an FDM channel. In this case, a serious single-tone interference caused by the mixing of the broadcast station and FDM channel carriers is experienced on one channel. However, the modulating frequencies of the broadcast signal can cause high noise also in the two channels on either side of the channel worst affected. As there is a frequency offset between the two carriers, the noise will usually be garbled. Further, the noise on the channels will vary with the broadcast station modulation. The second type of interference results from the broadcast station being assigned a frequency that falls between two FDM channels, resulting in a coherent signal being heard as noise on one channel. A second channel will have approximately the same noise reading, but being on the other side of the broadcast frequency, will have inverted frequencies. Usually, the higher modulating frequencies at the broadcast station (above 4 kHz) will cause some noise on one high and one lower channel, resulting in high noise on four channels. When interference from the broadcast band is considered, it might be expected that a single broadcast station would affect four or five channels in a 600-channel FDM system. While this may occur when the interference is introduced into the baseband portion of the system, if introduced before translation is completed, it is possible for interference from one broadcast station to adversely affect four or five channels in each basic supergroup in the system. For a 600-channel system, there are 10 basic supergroups. Consequently, a single broadcast station has been known to adversely affect 40 to 50 FDM channels. Introduction of broadcast band interference can result from many different factors. some of which are-

(a) Equipment design deficiencies: poor grounding inside the equipment, filters not effective at broadcast band frequencies, and poor selection of interior cables.

(b) Equipment improperly grounded or general grounding system not effective at higher frequencies.

(c) Isolation transformers improperly used.

(d) Design deficiencies in cable terminations.

(e) Cables improperly installed.

(e) *Security devices.* Internal checks on security devices are beyond the scope of this manual. If the input of a security device appears normal and the output abnormal, unit substitution or checking ground wiring is the normal isolation procedure. If the device is multiple channel, interference associated with the unit would normally affect all channels. If a single channel is being interfered with, the problem is probably not associated with the security device.

(3) *Major component isolation procedures*.

(a) *Switching or patching facilities*. Since the switching and patching facilities are normally nonautomatic, interference problems are generally due to loose connections, worn cables, dirty contacts, improper grounding, incorrect patching or jumpering, and similar problems that can be isolated and resolved by careful operation and proper maintenance.

(b) *Interconnecting cables*. The key to isolation of multipair cable problems is to check for any new cables which may have been laid which could have resulted in damage to existing cables, newly assigned circuits in existing cables, and any vehicular traffic, usually in the vicinity of the station, which could have damaged the cables. Such traffic can cause damage to the cable insulation and -puncturing of the protective sheath, resulting in moisture seepage into the cable. Eventually, this moisture can cause internal (interpair and interpair) corrosion which leads to partial shorts, leaks, or a path to ground which may result in ground loops, crosstalk, and hum. The test procedure for

identification of cable grounding problems consists of disconnecting the cable between the sites and measuring the resistance between pairs and the resistance to ground for each cable pair. A suitable ohmmeter, impedance bridge, or megger can be used for this test. Interpair resistance indications of less than 10,000 ohms per loop mile or resistance readings to ground of less than 50,000 ohms is normally indicative of a faulty cable or cable pair. Coaxial cables are very susceptible to damage caused by heat, compression, or abrasion. When these occur, the results can be mismatches, loss of desired signal, or introduction of interfering signals. A floating shield caused by damage to the cable may result in unwanted signals being introduced into or radiated from the equipment or cable.

(c) *Power line.* If a battery operated, multiband radio is available, use it to trace the source of powerline problems, particularly if a defective insulator or transformer is suspected as the source. Usually, such interference will increase in intensity as the source is approached with the radio. Poor ground connections at the power poles can result in a power frequency hum in the communications equipment as a result of the common impedance in the ground loop. A rapid means of isolation, if this is suspected. particularly in dry, sandy soil, is to thoroughly wet the ground around power poles close to the station with a saline solution. If the problem .is powerline grounding, the interference will be reduced or eliminated. In the case of a broken insulator. hitting the suspected pole with a sledgehammer will cause a variation in the interference.

d. *Remedial Procedures.* The procedures which operating personnel can use in the correction of interference problems may be limited by available test equipment and maintenance level authorization. The following procedures, where authorized. may be used for the correction of the corresponding interference sources given in paragraph 4-3b (2) (b):

(1) *Ignition noise.*

(a) Identify the source of the ignition noise to the specific source such as privately-owned vehicles, lawn mowers, or similar gasoline-powered engines.

(b) Report this information to the level where remedial action can be taken. Such action may include restriction of the ignition noise sources from the communication site, installation of noise suppresser devices, or restricting their use to periods of low communications usage.

(2) *Radar.* Radars are sometimes located where they will sweep the area of a communications site. In the event that radar interference is encountered, the following procedures should be followed.

(a) Report interference to proper authorities.

(b) Initiate action for possible sector blanking of the radar signal or other reduction in the radiation of this signal.

(c) Relocate either the communications site or the radar, if practicable. In some cases, the solution could be as simple as a relocation of receive antennas.

(3) *Office equipment.* Qualified repairmen must be consulted to eliminate problems from these machines, including the assurance that the internal ground connections are properly maintained. Procedures follow:

(a) Identify specific equipment causing problems. A 3-wire power cord properly grounding the equipment may solve the problem. If it does not,

(b) Report interference.

(c) Initiate request for shielding or relocation.

(4) *Power lines.*

(a) Isolate the cause of interference to the most likely source, such as a power transformer or insulator, with procedures given in paragraph 43c(3)(c).

(b) Report this information to the responsible authority, such as the local facility engineer.

(5) *Cables.* Damaged cables must be replaced, or spare cables used. When the cause of the cable damage has been determined, appropriate steps can be taken to ensure that it does not happen again, including the erection of signs and barriers to prevent vehicular traffic over the cables. Corroded and loose connections can be corrected by cleaning and tightening. If this is not possible, reroute to another cable pair, if available.

(6) *Circuit components.* Problems which have been traced to faulty circuit components, such as line amplifier modules. will generally require the services of a repairman to test at the appropriate monitoring jack and replace or adjust as necessary. Patching may be required to bypass the particular equipment involved while this maintenance is being performed.

(7) *Equipment grounding.* All electrically operated equipment within the site must be maintained at ground potential by interconnection with the common station ground. At DCA facilities, a station ground must be maintained at the DCS standard and periodically measured by the supporting maintenance or engineering facility. Non-DCS transportable or mobile installations also require good grounds. but have special grounding problems associated with their temporary deployment. Grounding rods furnished with the equipment may not suffice in some areas. In sandy soils. use of buried copper plates to increase the contact area with the soil may be necessary. Also, all grounds may require regular attention in accordance

with local instructions, such as soil treatment with a chemical solution, if necessary. Special emphasis must be directed to the use of 3-wire grounding power cords for ancillary equipment and hand tools with the ground wire connected to the station ground.

(8) *RF signal level.* Intermodulation and crosstalk interference problems attributable to high signal level will require adjustment to eliminate the problems. Any attempt to adjust a signal level at the receiving station without a check of the levels throughout the system, however, may not solve the problem if it is caused by high signal level at channel, group, or supergroup levels of a previous station which has resulted in baseband overloading. Signal level adjustment can be undertaken while the channels are in service, depending on the severity of the interference problem, but usually this adjustment must be done out of service with test tones applied.

(9) *Interfering transmitters.* If it is determined that a station's own transmission is causing excessive interference to others and circumstances preclude a frequency change, a sideband change, or other similar solution, the interference problems could be reduced by a slight reorientation of the transmit antenna (if this is practicable) to move the interfering lobe away from the distant station suffering the interference. Another possible solution could be to adjust the beam shape. For example, if a "sloping V" antenna configuration is being employed as an HF transmitting antenna, it may be possible to decrease the apex angle of the antenna to an optimum value of 30 degrees. The effective change in beam shape may avoid transmission into a nearby receiver. Suggestions for such a change should be referred to senior station engineering staff.

(10) *Antennas and transmission lines.* Loose broken and corroded antenna and waveguide connections and tower guywires are a source of noise which can be reduced through regular periodic inspection, cleaning, tightening, and other maintenance measures. This is an important facet of installation and maintenance. For example, copper wire strung during hot weather conditions can become taut and snap during cold conditions, if it was too tightly strung. Antenna orientation can sometimes be varied slightly to avoid interference pickup. Waveguide pressurization should be periodically checked in accordance with the applicable specifications. In the case of open transmission lines, proper connection at installation, orientation in relation to possible noise sources, and constant line spacing are important to the reduction of interference problems.

e. Follow-On Procedures.

(1) The above procedures for the recognition, isolation, and remedy of EMC problems should be sufficient to detect and correct most of the less complex interference problems that normally occur to fixed and transportable facilities. Persistent, chronic occurrences of EMC problems, particularly those which may occur upon activation of new systems within a site, will require resolution by the supporting maintenance or engineering assistance personnel. However, it is essential that site operating personnel learn to recognize both EMC and ECM problems and to distinguish between them.

(2) Reporting procedures are contained in the following chapter.

CHAPTER 5

PROCEDURES FOR REPORTING OPERATIONAL EMC PROBLEMS

5-1. General

In the event that interference is encountered, it must be reported to proper authorities in accordance with instructions provided herein. Prior to submitting a report, the unit or facility concerned will:

a. Conduct an initial evaluation to explore the possibility of locally generated spurious signals or other technical difficulties which might have caused the interference.

b. Without delay, coordinate with colocated units or those in nearby areas to isolate possible sources. Any coordination undertaken should not delay submission of the initial incident report, which is required within 24 hours. The reporting unit will continue to investigate the incident after submission of the initial report. Any additional pertinent information discovered during this continuing investigation will be reported promptly to all recipients of the initial report.

5-2. Procedures

The following procedures will be used to insure Army compliance with (C) AR 105-3, "Reporting Meaconing, Intrusion, Jamming, and Interference (MIJI) of Electromagnetic Systems" (U).

a. Commands may issue supplemental instructions and procedures for the reporting, analyzing, evaluating, and disseminating of information concerning MIJI incidents.

b. Commands may abbreviate local formats to include only appropriate items in accordance with attachment to AR 105-3; however, the same number/letter designation as shown must be retained.

c. The affected unit or facility will provide the initial incident information by a dual-addressed message, via secure communications means through C-E channels, for action to the local USASA support unit and the local USACC/USACEEIA activity. Additional addressees may be included as considered necessary by the command. The purpose of this procedure is to alert the appropriate command echelon which has the necessary resources to assist in further identifying and/or resolving the problem locally. d. Upon determination by the command that the incident was probably hostile or, in the case of interference, was not readily identifiable, a formal MIJI report will be forwarded within 24 hours per instructions contained in AR 105-3. To reduce the reporting requirements of the affected operational unit or facility, it is recommended that the action addressees of the initial incident information message submit the formal MIJI report as a coordinated action and provide any additional pertinent information in the remarks section to more fully document details surrounding the incident.

e. Upon determination by the command that the interference was clearly unintentional and beyond resolution within the command, the frequency manager will initiate an interference report, in the format of the attachment to AR 105-3, to higher frequency assignment authorities in accordance with policies and procedures established by ACP and US SUPP-1 ( ), "Frequency Management;" and ACP 121 and SUPP-1 (), "Communications Instructions, General." Information addressees will include AFSPECOMMCEN, Kelly AFB, Texas; Commander, US Army Communications Command, ATTN: CC-OPS-OS; and Commander, US Army Communications-Electronics Engineering Installation Agency, ATTN: CCC-CED-EMEA, Fort Huachuca, Arizona 85613.

f. Upon determination by the command that the interference was a technical or operational electromagnetic incompatibility problem, pertinent information will be forwarded to US Army Communications-Electronics Engineering Installation Agency (USACEEIA), ATTN: CCC-CED-EMEA, with information copy to Commander, US Army Communications Command (USACC), ATTN: CCOPS-OS, Fort Huachuca, Arizona 85613:

(1) *For information*-when the problem is resolved within the local command.

(2) *For action*-when the problem is beyond resolution within the local command. USACEEIA will coordinate the assistance required to solve operational EMC problems in accordance with assigned responsibilities under the operational electromagnetic compatibility area of the Army EMCP (AR 11-13). Information copies will be forwarded to all concerned and include AFSPECOMMCEN, Kelly AFB, Texas.

g. Commands will forward a copy implementing instructions to: Commander, US Army Communications-Electronics Engineering Installation Agency, ATTN: CCC-CED-EMEA, Fort Huachuca,

Arizona 85613; Commander, US Army Security Agency, ATTN: IAFOR-E, Arlington Hall Station, Arlington, Virginia 22212; and the Air Force Special Communications Center, Kelly AFB, Texas 78241.

h. Requests for other assistance involving operational EMC problems, electromagnetic environmental surveys, and potential hazards to ammunition and fuel handling storage sites should be addressed to Commander, USACEEIA, ATTN: CCC-CED-EMEA. Requests for assistance involving suspected or potential electromagnetic radiation hazards to personnel should be addressed to the US Army Environmental Health Agency, ATTN: HSE-RL, Aberdeen Proving Ground, Maryland 21005, with an information copy to Commander, USACEEIA, ATTN: CCC-CEDEMEA, Fort Huachuca, Arizona 85613.

APPENDIX

DEFINITIONS

Absorption--Wave propagation energy losses due to conversion of wave energy to heat.

Adjacent channel, audio--An audio channel immediately above or below a specified audio channel.

Adjacent channel, RF-An RF channel immediately above or below a specified RF channel.

Analog system--A system of communications in which information is transferred in the form of a continuously variable waveform.

Arcing--A low-voltage, high current electrical discharge, as contrasted with sparking.

Amplitude modulation (AM)--A method of modulating a carrier wave to cause it vary in amplitude according to the modulating intelligence.

Bandwidth--The difference, expressed in Hz, between specific upper and lower limiting frequencies which are usually specified as the upper and lower half-power (3 dB) points of a system or network.

Binary--A system of numbers having two as its base. Used in digital data transmission systems and computers.

Broadband emission--An emission which has a spectral energy distribution sufficiently broad and continuous so that the response of the measuring receiver in use does not vary measurably when tuned over a specified number of receiver bandwidths.

Capacitive coupling--The means by which signals are transferred from one conductor to another through the capacitance existing between the conductors.

Characteristic curve--As applied to transistors and electron tubes, the relationships between the various voltages and currents as evidenced at the external connections; for example, the curves of base current versus collector current for a transistor.

Cochannel interference--Electromagnetic interference caused in one communication channel by a transmitter operating in the same channel. Corona-The discharge brought a out as a result of the ionization of air (or gas) surrounding a conductor.

Cross modulation--A type of Intermodulation due to the modulation of the carrier of the desired signal by an undesired signal wave. Occurs primarily as a result of nonlinearities in the RF circuitry of a receiver.

Desensitization--The effect of an undesired signal in the receiver band pass which causes reduction of the desired signal level. The gain reduction is generally due to overload or saturation of some portion of the receiver. Can also occur when an interfering signal causes undesired operation of the AGC system in the receiver.

Dielectric--An insulating material which essentially prohibits the flow of electrical current between conducting components of a network.

Dual-conversion receiver-A receiver in which RF to IF conversion is accomplished in two steps, employing two local oscillator/mixer systems and two IF amplifiers.

Decibel (dB)--A logarithmic unit used in communications work to express power ratios.

Diffractions--The process by which electromagnetic waves curve around edges and penetrate into the shadow region behind an opaque obstacle.

Digital system--A system of communications in which information is represented by a series of discrete signal elements or digits (binary or other).

Electromagnetic compatibility (EMC)--The ability of C-E devices, together with electromechanical devices, to operate in their intended operational environment without suffering or causing unacceptable degradation because of unwanted electromagnetic energy. EMC includes vulnerability to ECM.

Electromagnetic interference (EMI)--Interference is any electromagnetic emission causing undesirable responses which degrade, disturb, or disrupt the design function of devices or systems which employ electromagnetic energy. For frequency management purposes, the term "harmful interference" is used to denote any emission, radiation, or induction which endangers the functioning of a radionavigation service or of other safety services, or seriously degrades, obstructs, or repeatedly interrupts a radio communications service operating in accordance with international regulations. Additionally, the term "harmful interference" is used to denote that type of interference which actually causes circuit outage as opposed to interference which is purely a source of annoyance.

Electronic Warfare (EW)--Military action involving

the use of electromagnetic energy to determine, exploit, reduce, or prevent hostile use of the electromagnetic spectrum, and action which retains friendly use of the electromagnetic spectrum. There are three divisions within EW:

Electronic Warfare Support Measures (ESM): That division of EW involving actions taken to search for, intercept, locate, and immediately identify radiated electromagnetic energy for the purpose of immediate threat recognition.

Electronic Countermeasures (ECM): That division of EW involving actions taken to prevent or reduce an enemy's effective use of the electromagnetic spectrum. ECM includes:

1. *Jamming.* The deliberate radiation, radiation, or reflection of electromagnetic energy with one object of impairing the use of electronic devices, equipment, or systems being used by an enemy.

2. *Deception.* The deliberate radiation, radiation, alteration, absorption, or reflection of electromagnetic energy in a manner intended to mislead an enemy in the interpretation or use of information received by his electronic systems. There are two categories of deception:

a. *Manipulative.* The alteration or simulation of friendly electromagnetic radiations to accomplish deception.

b. *Imitative*. Introducing radiations into enemy channels which imitate his own emissions.

Electronic Counter-Countermeasures (ECCM): That division of electronic warfare (EW) involving actions taken to insure friendly effective use of the electromagnetic spectrum despite the enemy's use of EW.

Emission spectrum--The power versus frequency distribution of an emitted signal, including the fundamental frequency, associated sidebands, and all spurious emissions.

Frequency division multiplex (FDM)--A means by which two or more channels of information are transmitted and received simultaneously without mutual interference by virtue of assigning each channel a separate frequency within the total available frequency band.

Group loop--In an electrical system, a potentially detrimental circuit path formed by the interconnection. of two or more points that are nonimally at ground potential.

Harmonic frequency--An integral multiple of the fundamental frequency; that is, the frequencies of 2, 3, 4, 5, ... times the fundamental frequency.

Heterodyne-The combining (beating) together in an electrical circuit of two frequencies to produce new frequencies which are the sum and difference of the two original frequencies.

Image frequency--The frequency which differs from the tuned frequency of a receiver by an amount equal to twice the inermediate frequency (the first intermediate frequency of a dual conversion receiver) of the receiver. The image frequency can be above or below the receive tuned frequency depending on whether the local oscillator is set above or below the receiver tuned frequency. An unwanted signal at the image frequency may become an interfering signal.

Inductive coupling--The type of coupling in which the mechanism is mutual inductance between the interference source and the signal system; that is, the interference is induced in the signal system by a magnetic field produced by the interference source.

Intermodulation--The production of frequencies in the output of a nonlinear device equal to the sums and differences of the frequencies present at the input of the device, plus the sumsand differences of harmonics of the input frequencies. For example, if f_a and f_b are the frequencies of the two input signals, the output signal could contain signals at frequencies of f_a, f_b, $2f_a$, $3f_a$, $4f_a$. . . . , $2f_b$, $3f_b$, $4f_b$. . . . , $f_a \pm f_b$, $f_a \pm 2f_b$, $f_a \pm 3f_b$. . . . , $f_b \pm 2f_a$, $f_b \pm 3f_a$, $f_b \pm 4f_b$, and so forth; in general; $nf_a \pm mf_b$, where either n or m could be 0, 1, 2, 3 and so forth. The signal components thus generated are sometimes called "Intermodulation products" The "order" of the product is n + m; for example, $f_a + 2f_b$ is a third order Intermodulation product.

Ionization--The process which results in the formation of an atom, or molecularly bound group of atoms, in which one or more electrons have been gained or lost, resulting in an ion or ions, each having a net negative or positive charge.

Jamming--See Electronic Warfare Local oscillator-An oscillator, incorporated within the equipment, whose output is mixed with another frequency waveform for frequency conversion.

Magnetic field coupling--Identical with Inductive Coupling.

Nonlinear Element--An element in which the relationships between the output and input are not linear; that is, the element alters the input (voltage and/or current) waveform and produces an altered or distorted version of the input waveform. Some elements or devices are designed to be non-linear (such as mixers, detectors, and clippers) while some are linear under some conditions and nonlinear under other conditions (for example, a linear amplifier operating under designed conditions versus overdriven conditions resulting in waveform distortion). Distortion causes harmonics

of the input frequencies to appear at the output. For example, if f_a is the frequency of the input signal, the output signal could contain signals at f_a , $2f_a$, $3f_a$, $4f_a$, and so forth at various amplitudes. When two or more signals are simultanesouly inputted to a nonlinear element, the output will contain signals at frequencies that are the sums and differences of the fundamental and harmonics of the frequencies of the input signals. (See Intermodulation.)

Oscillator--A circuit that generates a periodic signal.

Parasitic oscillation--An undesirable oscillation occurring in RF amplifiers or oscillators, usually caused by the change in impedance of circuit elements, at frequencies remote from the normal operating frequencies.

Pulse repetition frequency (PRF)--In pulsed radar or any other system employing periodic pulses, the number of pulses occurring each second, expressed in Hz.

Receiver response--The manner in which a receiver reacts to wanted and unwanted signals.

Rectification--Essentially, the process of converting ac to dc.

Refraction--The change of direction, or apparent bending experienced by an electromagnetic wave as it passes obliquely from one medium to another or through a medium having nonuniform density. An example is the wave bending effect which occurs as an electromagnetic wave passes through the ionosphere. Saturation--The condition in any circuit that exists when an increase in the input produces no further change in the output; for example, an electron tube driven into th saturation region by too large an input signal.

Shielding--The surrounding of electrical components with a conducting medium, such as aluminum, to reduce the capacitive and inductive coupling of undesired signals from one circuit to another.

Shot effect--A troublesome phenomenon which causes sputtering or popping noises in electronic equipment due to variations in the number of electrons emitted per second from the cathode of an electron tube and instantaneous variation in the distribution of the electrons among the tube electrodes.

Single-conversion receiver--A receiver employing one local oscillator and one mixer stage for conversion to a single intermediate frequency (IF) as opposed to a double conversion receiver which uses two intermediate frequencies.

Sparking--The sudden breakdown of the insulating strength of the dielectric separating two electrodes, accompanied by a rush of electrical current across the "spark gap," and a flash of light indicating very high temperature. Unlike the arc, the spark is of very short duration. Spurious emission-Any unwanted emission from a transmitter.

Spurious response--Any response of a receiver to frequencies outside the designated reception bandwidth.

Squelch--To automatically disable the audio output of a receiver when the incoming RF signal falls below a preset level, or is absent.

Susceptibility--The degree to which a device, equipment, or weapon system is open to effective attack due to one or more inherent weaknesses. Thermal agitation-Random movement of electrons within a conductor as a result of heat which may cause unacceptable noise within the circuit.

Thermostatic device--A device which operates in response to temperature variations. An example is a thermostatically controlled switch.

Time division multiplex (TDM)--A means by which two or more channels of information are transmitted and received simultaneously without mutual interference by virtue of assigning each channel specific time intervals within the total unit time available.

Transients--Momentary fluctuations of voltage and current in a circuit. They may be the result of a disturbance such as opening or closing a switch, a keying apparatus, or noise sources.

Troposphere--A thermal atmospheric region, extending from the earth's surface to the ionosphere, characterized by decreasing temperature with height, appreciable vertical wind motion, vapor content, and weather phenomena.

Vulnerability--The characteristics of C-E devices, together with electromechanical devices, which cause them to suffer degradation of performance as a result of having been subjected to intentional electromagnetic interference in a manmade, hostile environment.

White noise--A complex wave consisting of many radio frequencies. Its energy content is relatively constant per unit bandwidth across the RF spectrum.

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***NG*: State AG (2); Units: Same as Active Army except 1 copy to each unit.**
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For explanation of abbreviations used, see AR 310-50.

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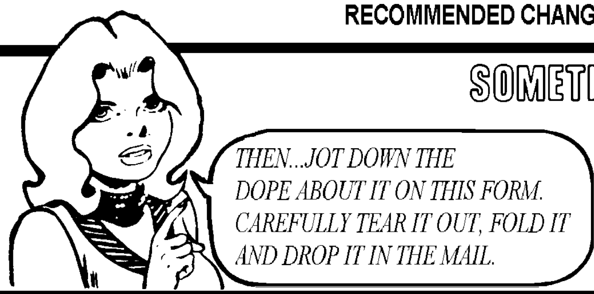

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The Metric System and Equivalents

Linear Measure

1 centimeter = 10 millimeters = .39 inch
1 decimeter = 10 centimeters = 3.94 inches
1 meter = 10 decimeters = 39.37 inches
1 dekameter = 10 meters = 32.8 feet
1 hectometer = 10 dekameters = 328.08 feet
1 kilometer = 10 hectometers = 3,280.8 feet

Weights

1 centigram = 10 milligrams = .15 grain
1 decigram = 10 centigrams = 1.54 grains
1 gram = 10 decigram = .035 ounce
1 decagram = 10 grams = .35 ounce
1 hectogram = 10 decagrams = 3.52 ounces
1 kilogram = 10 hectograms = 2.2 pounds
1 quintal = 100 kilograms = 220.46 pounds
1 metric ton = 10 quintals = 1.1 short tons

Liquid Measure

1 centiliter = 10 milliters = .34 fl. ounce
1 deciliter = 10 centiliters = 3.38 fl. ounces
1 liter = 10 deciliters = 33.81 fl. ounces
1 dekaliter = 10 liters = 2.64 gallons
1 hectoliter = 10 dekaliters = 26.42 gallons
1 kiloliter = 10 hectoliters = 264.18 gallons

Square Measure

1 sq. centimeter = 100 sq. millimeters = .155 sq. inch
1 sq. decimeter = 100 sq. centimeters = 15.5 sq. inches
1 sq. meter (centare) = 100 sq. decimeters = 10.76 sq. feet
1 sq. dekameter (are) = 100 sq. meters = 1,076.4 sq. feet
1 sq. hectometer (hectare) = 100 sq. dekameters = 2.47 acres
1 sq. kilometer = 100 sq. hectometers = .386 sq. mile

Cubic Measure

1 cu. centimeter = 1000 cu. millimeters = .06 cu. inch
1 cu. decimeter = 1000 cu. centimeters = 61.02 cu. inches
1 cu. meter = 1000 cu. decimeters = 35.31 cu. feet

Approximate Conversion Factors

To change	*To*	*Multiply by*	*To change*	*To*	*Multiply by*
inches	centimeters	2.540	ounce-inches	Newton-meters	.007062
feet	meters	.305	centimeters	inches	.394
yards	meters	.914	meters	feet	3.280
miles	kilometers	1.609	meters	yards	1.094
square inches	square centimeters	6.451	kilometers	miles	.621
square feet	square meters	.093	square centimeters	square inches	.155
square yards	square meters	.836	square meters	square feet	10.764
square miles	square kilometers	2.590	square meters	square yards	1.196
acres	square hectometers	.405	square kilometers	square miles	.386
cubic feet	cubic meters	.028	square hectometers	acres	2.471
cubic yards	cubic meters	.765	cubic meters	cubic feet	35.315
fluid ounces	milliliters	29,573	cubic meters	cubic yards	1.308
pints	liters	.473	milliliters	fluid ounces	.034
quarts	liters	.946	liters	pints	2.113
gallons	liters	3.785	liters	quarts	1.057
ounces	grams	28.349	liters	gallons	.264
pounds	kilograms	.454	grams	ounces	.035
short tons	metric tons	.907	kilograms	pounds	2.205
pound-feet	Newton-meters	1.356	metric tons	short tons	1.102
pound-inches	Newton-meters	.11296			

Temperature (Exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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